

CRITICAL PATH ROADMAP (CPR)

BASELINE DOCUMENT

OCTOBER 2000

This document is the official version of the current Critical Path Roadmap (CPR). It has been reviewed by the Critical Path Control Panel (CPCP), and is endorsed by all members as indicated by the signatures of the Chairperson and Deputy Chairperson (shown below). Any changes to the document must adhere to the policies and procedures outlined in the CPR Charter. The document will be issued on an annual basis. It will track changes to its content; the material contained in the CPR Web Site will parallel this document.

*The following CPR items are under configuration control (Boldface indicates **current** configuration control items).*

- **Taxonomy**
- **Risk Areas**
- **Risks**
- **Risk Factors**
- **Critical Questions**
- **Risk Ranking and Cross Risk Prioritization**
- **Critical Question Priorities**
- Deliverables (Risk Mitigations)
- Risk Mitigation Requirements
- **Roadmaps**

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1.0 Introduction

This document serves as the baseline version of the Critical Path Roadmap (CPR). It provides background information about the CPR and presents its structure and content in detail. Subsequent changes to this document (i.e., the structure and the content of the CPR) shall be under the jurisdiction of the Critical Path Control Panel (CPCP). The elements listed in this document, and any subsequent changes, shall be reflected also in the complimentary CPR web site (<http://http:Criticalpath.jsc.nasa.gov>).

2.0 Background

Approximately three years ago, the Agency's lead center for the human elements of spaceflight (the Johnson Space Center), along with the National Space Biomedical Research Institute (NSBRI) (which has the lead role in developing countermeasures) initiated an activity to identify the most critical risks confronting extended human spaceflight missions. Two salient factors influenced this activity: first, what is needed to enable a go/no go decision for embarking on extended human spaceflight missions; and second, what is needed to address known and potential health, safety and performance risks associated with human exploration class missions (Table 1).

TABLE 1. Mars Design Reference Mission.

Earth Departure	2014
Out Transit	161 Days
Mars Surface Stay	569 Days
Return Transit	154 Days
4 G Transitions	1G to 0G; 0G to 1/3G; 1/3G to 0G; 0G to 1G
High G Loading	3-5 (TBD)G During Aerobraking and Landing
Crew Size	6

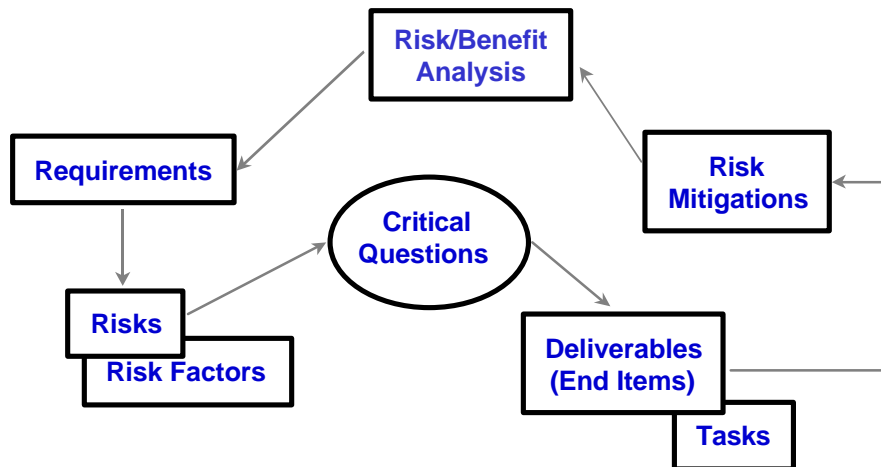
A unique approach was used to identify, assess and prioritize the biomedical risks and the required mitigations necessary to prevent the occurrence of the risk or to reduce its impact should it occur on such a mission. The Critical Path Roadmap, represents an opportunity to develop and implement a focused and

evolving program of research and technology designed from a “risk reduction” perspective to prevent or reduce the risks to humans exposed to the space environment. It provides the means to identify, characterize, and mitigate the critical risks associated with exposure to the spaceflight environment to an acceptable level that ensures the ability to accomplish human exploration class missions. It will provide information to the Agency’s advanced planning decision to proceed with human exploration-class missions. It lays the foundation for a process leading to a set of decision criteria, or metrics, that can be used to determine program or project emphasis, resources, and timing, thus providing management from risk assessment through outcome.

3.0 Key Elements of the Critical Path Roadmap

The key elements of the CPR and their interrelationship are shown in Figure 1. All elements are driven initially by the set of mission requirements (see Table 1). These requirements set the context for what risks must be addressed and to what acceptable level.

Figure 1. Key Elements of the Critical Path Roadmap



3.1 Risks

Definition

Risks are the conditional probability of the occurrence of an adverse event from exposure to the space environment. Such exposure can result in dysfunctional physiological or behavioral adaptation that could lead to increased injuries, illness, or loss of life and/or mission objectives. Discipline risk area teams identified the most critical risks in their respective disciplines and assessed each risk using a set of risk scoring criteria and determined the rank order of the risks within their discipline.

Risk Scoring Criteria

A set of five criteria was developed to assess the significance and severity of each risk. These included: the probability of occurrence of the risk (with and without current countermeasures); the impact of the risk on crew health and performance; the impact of the risk on accomplishment of mission objectives; and the overall status of the risk mitigation. The specific risk scoring criteria are shown in Appendix A-1.

Rank Ordering of Risks

Each discipline risk area team rank-ordered the risks within their discipline using the risk scoring assessments and discussion among the team members. Teams could assign the same rank order to more than one risk.

Cross-Risk Prioritization

A separate panel of eight members reviewed and prioritized the risks, across disciplines, using the discipline experts' assessments. A categorization comparing the relative importance of risks in terms of what is known about the risk and its mitigation was developed to illustrate different types of risks. Risks were classified as Type I, Type II, and Type III risks. The Risk Matrix showing the assignment of risk types/priorities is contained in Figure 2.

Figure 2. Assignment of Risk Types/Priorities

	Demonstrated Serious Problem	Suspected Serious Problem	Demonstrated Problem	Suspected Problem
No Countermeasure (CM) Concept	I	II	II or III	III
CM Concept - No Ground Validation	II	II	II or III	III
CM Concept - No Space Verification	III	III	III	III
Effective & Operational CM	IV	Not applicable	IV	Not applicable

3.2 Risk Factors

Definition

Risk factors represent conditions associated with an increased probability of the occurrence of the risk and can operate singly, or in combination, to contribute to the risk's occurrence. Each risk has a set of risk factors that may be common to more than one risk. Examples of risk factors are stress, diet, gender, and age.

3.3 Critical Questions

Definition

Critical questions encompass the key research and technology issues that must be addressed to understand and mitigate the risk. Questions can address risk assessment and acceptability, underlying mechanisms, countermeasure development and validation, and medical diagnosis and treatment. Each risk has a set of critical questions that have been prioritized by the discipline risk area teams in terms of their relative importance for addressing the specific risk. Questions are unique to a risk area but not necessarily to more than one risk.

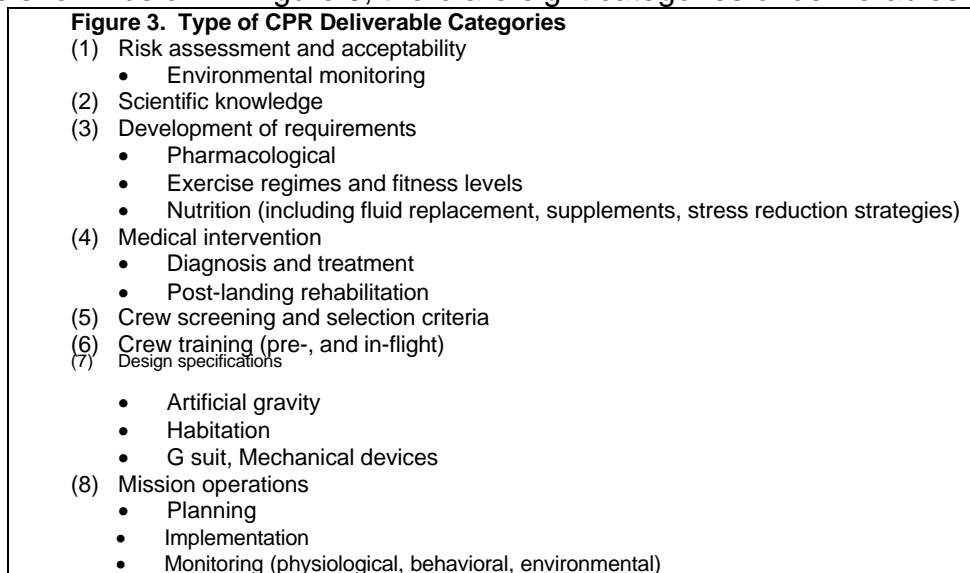
3.4 Deliverables

Definition

Deliverables represent the specific end-items that can be identified, completed, and made available at known dates. CPR deliverables can represent the following: scientific knowledge about underlying mechanisms; risk acceptability standards; countermeasure protocols, strategies, or procedures for risk reduction or mitigation (e.g., nutritional, pharmacological); or technology development (e.g., models, instruments, devices, g suits).

Types of Deliverables

As shown below in Figure 3, there are eight categories of deliverables.

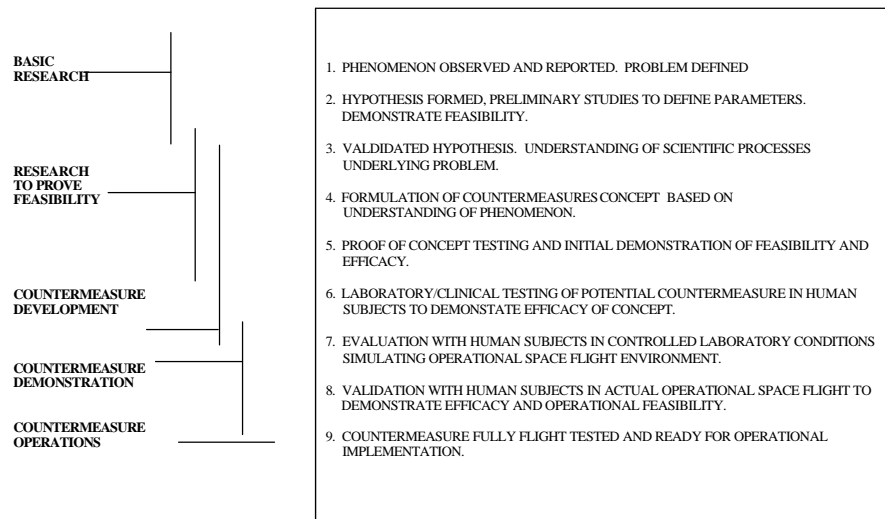


Readiness Levels

Readiness levels refer to the maturity of the countermeasure deliverable. Each of the nine levels of readiness reflect a greater degree of development, definition and validation from initial hypothesis testing to prototype development in relevant environments to fully flight-tested and ready for operational implementation.

Figures 4 and 5 show the countermeasure and technology readiness levels and definitions for the CPR deliverables.

Figure 4. Countermeasure Readiness Levels



Source: NASA Life Sciences Division
Office of Life and Microgravity Sciences Applications

Figure 5. Technology Readiness Levels (TRL)

Level	Definition
TRL1	Basic principles observed
TRL2	Technology concept and/or application formulated
TRL3	Analytical and experimental critical function/proof-of-concept
TRL4	Component and/or breadboard validation in lab
TRL5	Component and/or breadboard in relevant environment
TRL6	System/subsystem model or prototype demonstration in relevant environment
TRL7	Subsystem prototype in a space environment
TRL8	System completed and flight qualified through demonstration
TRL9	System flight proven through mission operations

3.5 Risk Mitigation Requirements

Definition

A risk mitigation requirement is the statement of the requirement for a CPR deliverable that has been tested, validated and completed. It may appear as a flight rule or a SLSD “requirements” document.

3.6 Risk/Benefit Analysis

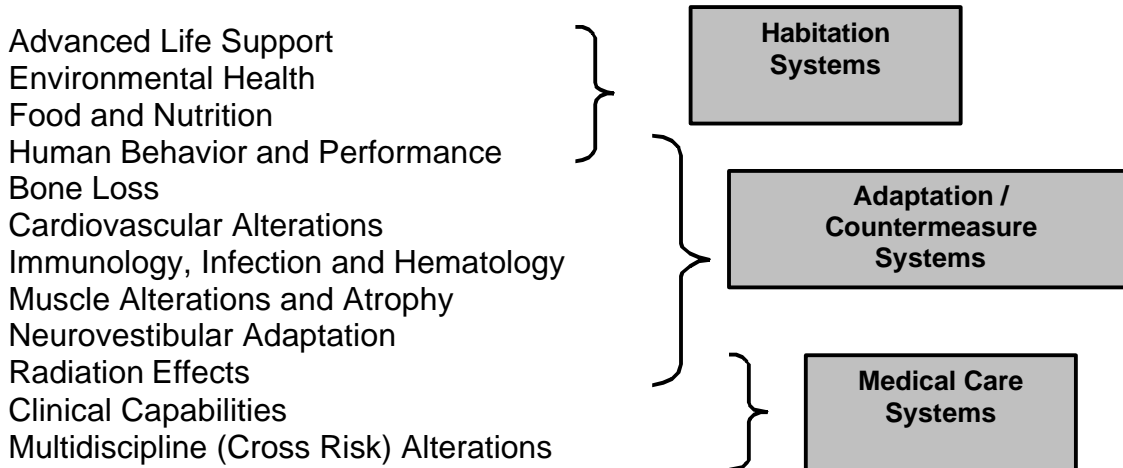
Once risks have been identified, characterized and prioritized, the next step is the evaluation of a range of options and selection of outcomes. This step is referred to as risk, or cost/benefit analysis, and is important in resource allocation decisions. The knowledge of what is needed to better understand and mitigate the risk, to what level of acceptability, the development/readiness level of the mitigation or deliverable, mission parameters and other resources such as crew time, power and space, are part of the decisionmaking process.

4.0 CPR Approach and Results

Informed decisions about risk reduction options are the combination of two interacting processes – analysis and deliberation. While there are no set rules on how to achieve the right balance, both are necessary to reduce risk. The CPR was based on an iterative process that incorporated review, analysis, and deliberations throughout the process.

4.1 Risk Identification and Characterization

As previously mentioned, the CPR was initiated approximately three years ago as a JSC intramural activity to identify the biomedical risks associated with long duration human exploration class missions. Following a six-month period of risk identification, the National Space Biomedical Research Institute (NSBRI) began to participate in the effort. Co-leads (JSC and NSBRI) for the 12 disciplines were named to the following areas:



The 12 discipline areas are related to the following three functional elements: (1) crew *habitation systems* that are life-sustaining systems to protect the crew from

direct hazards associated with living in space (e.g., air, water, thermal, vacuum, radiation, etc.); (2) *Adaptation/Countermeasure systems* that aid the crew in adapting to the microgravity conditions by preventing physiological or psychological deterioration (e.g., exercise regimes, medications, social support); and, (3) *medical care systems* that provide diagnosis and treatment capabilities for ensuring crew health (e.g., biosensors, biological assays for laboratory diagnostics, medical equipment, expert decisionmaking systems, telemedicine).

Critical risks were identified for each area as well as a set of core critical questions. Currently there are 55 critical risks and 339 critical questions (See Table 2.). Appendix 3 contains the list of all 55 CPR risks, their rank order rating within each discipline risk area, and their prioritization across risks (Risk Type). Risk Data Sheets, including risk definition, are presented in Appendix A-2.

Table 2. SUMMARY OF NUMBER OF RISKS, AND CRITICAL QUESTIONS FOR EACH DISCIPLINE RISK AREA (UNIQUE AND TOTAL NUMBER)

Risk Area	No. Risks	No. Critical Questions (Total)	No. Critical Questions (Unique)
Advanced Life Support	7	40	40
Bone Loss	4	34	23
Cardiovascular Alterations	5	20	20
Environmental Health	3	26	13
Food & Nutrition	4	27	18
Human Behavior & Performance	4	22	21
Immunology, Infection & Hematology	6	48	30
Muscle Alterations & Atrophy	5	15	9
Neurovestibular Adaptation	5	29	21
Radiation Effects	5	40	13
Clinical Capabilities	6	39	39
Multisystem (Cross Risk) Alterations	1	3	3
Totals	55	343	250

The following section contains separate tables for the risks in each of the 12 risk areas (e.g., Advanced Life Support; Bone Loss; Cardiovascular Alterations). For tracking purposes, each risk was assigned a risk identification number (e.g., 1, 9, 55) that appears in the first column of each table. The risk title represents the name of the risk, as currently configured. Risk factors associated with each risk are listed in each of the tables. Risk rank within the discipline risk area is shown as well for each risk. The classification of a risk as a Type I, Type II or Type III risk is shown in the tables also. Risks are listed by rank order and by Type.

5.0 Risk Area Risks, Risk Factors, Risk Ranks and Risk Type

5.1 Advanced Life Support

Risk ID No. ¹	Risk Title ²	Risk Factors ³	Risk Rank ⁴	Risk Type ⁵
1	Inability to Maintain Acceptable Atmosphere in Habitable Areas	Remoteness, Crew health/susceptibility to degree of system closure	1	II
53	Inadequate Nutrition (Malnutrition) Due to Inability to Provide and Maintain a Bioregenerative System	Not specified	1	II
2	Inability to Provide and Recover Potable Water	Remoteness, Crew health/susceptibility to degree of system closure	2	II
3	Inadequate Supplies (including maintenance, emergency provisions, and edible food)	Not specified	2	II
4	Inability to Maintain Thermal Balance in Habitable Areas	Sources of heat from other elements of the mission; Orientation of the vehicle during flight; Orientation of vehicle and/or habitat on planetary surface; Location on planetary surface; Planetary environment (temperature ranges & extremes, dust, seasonal variations, etc.); Use or availability of local planetary resources	3	II
5	Inability to Adequately Process Solid Wastes	Not specified	3	II
6	Inadequate Stowage and Disposal Facilities for Solid and Liquid Trash Generated During Mission	Not specified	4	II

5.2 Bone Loss

Risk ID No. ¹	Risk Title ²	Risk Factors ³	Risk Rank ⁴	Risk Type ⁵
9	Acceleration of Age-Related Osteoporosis	Age; Recovery rate postflight; Gender; Baseline BMD; Diet	1	I
10	Fracture and Impaired Fracture Healing	Poor nutrition; Decreased muscle mass; Muscle/bone strength imbalance; Endocrine dysfunction	2	II
11	Injury to Soft Connective Tissue, Joint Cartilage, & Intervertebral Disc Rupture w/ or w/o Neurological Complications	Decreased muscle strength; Decreased loads on muscle and connective tissue; Muscle atrophy and bone/mineral loss; Biomechanical disturbances	3	III
12	Renal Stone Formation	Inflight overloaded schedule, motion sickness on return to 1 g, decreased skeletal loads inflight, hypercalcuria risk throughout flight, decreased urine volume, increased bone resorption	4	III

¹ The unique number assigned to each risk to track the risk

² The statement, or title, of each risk

³ The list of risk factors associated with each risk

⁴ The assigned rank order of the risk determined by expert analysis and deliberations

⁵ Classification of a risk into one of three categories determined through expert analysis and deliberations

5.3 Cardiovascular Alterations

Risk ID No.¹	Risk Title²	Risk Factors³	Risk Rank⁴	Risk Type⁵
13	Occurrence of Serious Cardiac Dysrhythmias	Fluid and Electrolyte Imbalance; Diminished Cardiac Mass	1	II
14	Impaired Cardiovascular Response to Orthostatic Stress	Plasma fluid shift; Fluid intake; Altered hemodynamic regulation; Changes in vascular compliance	1	II
15	Diminished Cardiac Function	Reduction of stress on heart over prolonged period in weightlessness	2	III
16	Manifestation of Previously Asymptomatic Cardiovascular Disease	Lack of sufficiently sensitive screening measures	3	III
17	Impaired Cardiovascular Response to Exercise Stress	Diminished Cardiac Function; Decreased blood volume	4	III

5.4 Environmental Health

Risk ID No.¹	Risk Title²	Risk Factors³	Risk Rank⁴	Risk Type⁵
51	Inability to Maintain Acceptable Atmosphere in Habitable Areas Due to Environmental Health Contaminants	Remoteness; Crew health/susceptibility to degree of system closure	1	II
52	Inability to Provide and Recover Potable Water Due to Environmental Health Contaminants	Remoteness; Crew health/susceptibility to degree of system closure	2	II
50	Allergies and Hypersensitivity Reactions from Exposure to the Enclosed Spacecraft & Other Environmental Factors	Chemically sensitive individuals or altered immune responses; Impaired pulmonary capacity	3	II

5.5 Food and Nutrition

Risk ID No.¹	Risk Title²	Risk Factors³	Risk Rank⁴	Risk Type⁵
7	Inadequate Nutrition (Malnutrition)	Inadequate nutritional requirements; Inability to provide food; Improper food intake; Stress; Countermeasure induced-alterations in nutrient requirements	1	II
8	Unsafe Food Systems	Chemical or microbial contamination; Packaging; Environmental control	2	II
55	Human Performance Failure Due to Nutritional Deficiencies	Malnutrition; Inadequate nutrition requirements; Stress; Boredom	3	II
54	Difficulty of Rehabilitation Following Landing Due to Nutritional Deficiencies	Bone loss; Renal disease; Infectious disease; Radiation biochemical changes; Muscle wasting; Decreased red blood cell mass	4	III

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² The statement, or title, of each risk

³ The list of risk factors associated with each risk

⁴ The assigned rank order of the risk determined by expert analysis and deliberations

⁵ Classification of a risk into one of three categories determined through expert analysis and deliberations

5.6 Human Behavior and Performance

Risk ID No.¹	Risk Title²	Risk Factors³	Risk Rank⁴	Risk Type⁵
18	Human Performance Failure Because of Poor Psychosocial Adaptation	Psychosocial Adaptation	1	I
19	Human Performance Failure Because of Sleep and Circadian Rhythm Problems	Sleep and Circadian Rhythms	2	II
20	Human Performance Failure Because of Human System Interface Problems & Ineffective Habitat, Equipment, Design, Workload, or Inflight Information and Training Systems	Human-Systems Interface; Habitability; Information Management and Training	3	III
21	Human Performance Failure Because of Neurobehavioral Dysfunction	Behavioral Health	4	III

5.7 Immunology, Infection and Hematology

Risk ID No.¹	Risk Title²	Risk Factors³	Risk Rank⁴	Risk Type⁵
22	Immunodeficiency/Infections	Stress; Radiation exposure; Decreased cell function; Altered environmental exposure	1	III
23	Carcinogenesis Caused by Immune System Changes	Radiation exposure; Chemical exposure; Viruses	1	III
24	Altered Hemodynamic and Cardiovascular Dynamics caused by Altered Blood Components	Loss of plasma and red blood cells due to exposure to microgravity	1	III
25	Altered Wound Healing	Not specified	2	III
26	Altered Host-Microbial Interactions	Spacecraft environmental factors; Host defense factors; Nutrition	3	III
27	Allergies and Hypersensitivity Reactions	Exposure to environmental agents (chemical/biological); Autoimmune disease	3	III

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³ The list of risk factors associated with each risk

⁴ The assigned rank order of the risk determined by expert analysis and deliberations

⁵ Classification of a risk into one of three categories determined through expert analysis and deliberations

5.8 Muscle Alterations and Atrophy

Risk ID No. ¹	Risk Title ²	Risk Factors ³	Risk Rank ⁴	Risk Type ⁵
28	Loss of Skeletal Muscle Mass, Strength, and/or Endurance	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)	1	II
29	Inability to Adequately Perform Tasks Due to Motor Performance, Muscle Endurance, and Disruption in Structural and Functional Properties of Soft & Hard Connective Tissues of the Axial Skeleton	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)	1	II
30	Inability to Sustain Muscle Performance Levels to Meet Demands of Performing Activities of Varying Intensities	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)	2	II
31	Propensity to Develop Muscle Injury, Connective Tissue Dysfunction, and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength and Muscular Fatigue	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance	3	III
32	Impact of Deficits in Skeletal Muscle Structure and Function on Other Systems	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)	NR*	III

*NR: Not rated by discipline risk area team

5.9 Neurovestibular Adaptation

Risk ID No. ¹	Risk Title ²	Risk Factors ³	Risk Rank ⁴	Risk Type ⁵
33	Disorientation and Inability to Perform Landing, Egress, or Other Physical Tasks, Especially During/After G-Level Changes (Acute spontaneous & provoked vertigo, nystagmus, oscillopsia, poor dynamic visual acuity)	Sleep disorders; Sleep disruption; Circadian dysrhythmia; Impaired cognitive or psychomotor performance; Space motion sickness	1	II
34	Impaired Neuromuscular Coordination and/or Strength (Gait ataxia, postural instability)	Sleep disorders; Sleep disruption, Circadian dysrhythmia; Impaired cognitive or psychomotor performance; Space motion sickness	2	II
35	Impaired Cognitive and/or Physical Performance Due to Motion Sickness Symptoms or Treatments, Especially During/After G-Level Changes (Including short term memory loss, reaction time increase, drowsiness, fatigue, torpor, irritability, ketosis)	Change in gravity levels	3	III
36	Vestibular Contribution to Cardiorespiratory Dysfunction (Postlanding orthostatic intolerance, sleep and mood changes)	Return to 1 G	4	III
37	Possible Chronic Impairment of Orientation or Balance Function Due to Microgravity or Radiation (Imbalance, gait ataxia, vertigo, chronic vestibular insufficiency, poor dynamic visual acuity)	Radiation exposure; Prolonged exposure to microgravity	5	III

1 The unique number assigned to each risk to track the risk

2 The statement, or title, of each risk

3 The list of risk factors associated with each risk

4 The assigned rank order of the risk determined by expert analysis and deliberations

5 Classification of a risk into one of three categories determined through expert analysis and deliberations

5.10 Radiation Effects

Risk ID No.¹	Risk Title²	Risk Factors³	Risk Rank⁴	Risk Type⁵
38	Carcinogenesis Caused by Radiation	Genetic susceptibility; Nutrition; Immune function; Growth factors; Stress; Environmental mutagens; Age; Gender	1	I
39	Damage to Central Nervous System from Radiation Exposure	Genetic susceptibility; Extracellular milieu; Environmental toxic agents	2	II
40	Synergistic Effects from Exposure to Radiation, Microgravity and other Spacecraft Environmental Factors	Microgravity or weightlessness; Genetic susceptibility; Environmental cytotoxic and mutagenic compounds	3	II
41	Early or Acute Effects from Radiation Exposure	Genetic susceptibility; Stress; Immune function; Environmental toxic agents	4	II
42	Radiation Effects on Fertility, Sterility, and Heredity	Genetic susceptibility; Age; Gender; Environmental toxic agents	5	III

5.11 Clinical Capabilities

Risk ID No.¹	Risk Title²	Risk Factors³	Risk Rank⁴	Risk Type⁵
43	Trauma and Acute Medical Problems	Prolonged exposure to microgravity and transitions to altered gravity levels upon landing on planetary surfaces; Isolated and confined environment; Highly autonomous operations with delayed communications	1	I
44	Toxic Exposure	Enclosed spacecraft; Chemical leak; Increased or altered sensitivity of individuals to environmental agents; Allergies; Stress; Changes in immune system response; Inadequate ALS; Prolonged dwelling in an enclosed environment	2	II
45	Altered Pharmacodynamics and Adverse Drug Reactions	Polypharmacy (multidrug administration); Idiosyncratic tendencies; Allergies; Pharmacotherapeutic changes in microgravity (e.g., adsorption changes metabolism; Drug effect changes-SMS)	3	II
46	Illness and Ambulatory Health Problems	Prolonged exposure to microgravity and transitions to altered gravity levels upon landing on planetary surfaces; Isolated and confined environment; Highly autonomous operations with delayed communications	4	III
47	Development and Treatment of Space-Related Decompression Sickness	Deconditioning, Improper EVA operations, Musculoskeletal pain due to bends	5	III
48	Difficulty of Rehabilitation Following Landing	Reentry into higher gravitational forces; Fluid loading; Exercise; Fitness; G-suit; Deconditioning; Impaired response to orthostatic stress; Vestibular contributions to cardioregulatory dysfunction; Possible chronic impairment of balance function; Muscle performance; Endurance or strength impairment	6	III

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⁵ Classification of a risk into one of three categories determined through expert analysis and deliberations

5.12 Multisystem (Cross Risk) Alterations

Risk ID No.¹	Risk Title²	Risk Factors³	Risk Rank⁴	Risk Type⁵
49	Post-landing Alterations in Various Systems Resulting in Severe Performance Decrements and Injuries	Reentry into higher gravitational forces; Fluid loading; Exercise; Fitness; G-suit; Deconditioning; Impaired response to orthostatic stress; Vestibular contributions to cardioregulatory dysfunction; Possible chronic impairment of balance function; Muscle performance; Endurance or strength impairment; Prolonged exposure to microgravity and transitions to altered gravity levels upon landing on planetary surfaces; isolated and confined environment; highly autonomous operations with delayed communications	1	II

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⁴ The assigned rank order of the risk determined by expert analysis and deliberations

⁵ Classification of a risk into one of three categories determined through expert analysis and deliberations

6.0 Risks, Critical Questions, Question Priorities and Categories

Each risk has a set of critical questions that must be addressed in order to mitigate the risk. Each question was prioritized by the risk area discipline experts in terms of its relative importance for addressing and mitigating the risk. The priority score is based on a 1 – 4 scale; “1” represents highest priority and “4” relatively lower priority. In addition, each question was categorized in terms of the type of research or technology effort it represents (i.e., assessment, mechanisms, countermeasures, or medical diagnosis and treatment). These categories relate to deliverables as well. The following section presents the critical question information for each of the 55 risks by the 12 discipline risk areas. (The key for the information contained in the tables is presented at the end of the each risk area section.)

6.1 Advanced Life Support

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Inability to Maintain Acceptable Atmosphere in Habitable Areas (Risk No. 1)	1.01	What is the best method for controlling total atmospheric pressure, O2 and CO2 partial pressure?	2	Countermeasures
	1.02	What is the best CO2 adsorbing material and/or mechanism?	2	Countermeasures
	1.03	What is the best way to recover the O2 from the CO2?	2	Countermeasures
	1.04	What is the best way to control trace contaminants?	2	Countermeasures
	1.05	Are sensors available to provide environmental data?	3	Countermeasures
	1.06	Are sensors available to monitor performance?	3	Countermeasures
	1.07	What is the best monitoring and control system?	3	Countermeasures
Inability to Provide and Recover Potable Water (Risk No. 2)	1.16	What is the best method for supplying potable water to use points?	3	Countermeasures
	1.17	What waste water collection and transport mechanisms are best?	3	Countermeasures
	1.18	What methods are best for removal of organic and inorganic contaminants in waste water (physicochemical, biological)?	2	Countermeasures
	1.19	What is the best method to add a residual biocide?	3	Countermeasures
	1.20	What is the best way to store and maintain potability of recycled water?	2	Countermeasures
	1.21	What methods (sensors) are available to measure water quality parameters?	3	Countermeasures
	1.22	What is the best monitoring and control system?	3	Countermeasures
Inadequate Supplies (including maintenance, emergency provisions, and edible food) (Risk No. 3)	1.45	What storm shelter supplies must be provided to allow the crew to survive radiation threats requiring retreat into safe areas for prolonged time periods?	3	Countermeasures

6.1 Advanced Life Support (continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Inability to Maintain Thermal Balance in Habitable Areas (Risk No. 4)	1.23	What is the best thermal working fluid for the thermal control components in habitable areas?	3	Countermeasures
	1.24	What materials and designs are best used to acquire waste heat (condensing heat exchangers, coldplates, etc.)?	3	Countermeasures
	1.25	What material and designs are best for the thermal transport components (pumps, phase separators, etc.)?	3	Countermeasures
	1.26	What materials and designs are best for the thermal rejection components (radiators for use on vehicles vs moon and Mars)?	2	Countermeasures
	1.27	What is the best way to control humidity?	3	Countermeasures
	1.28	Are sensors available to provide environmental data?	3	Countermeasures
	1.29	Are sensors available to monitor performance of the thermal system?	3	Countermeasures
	1.30	What is the best monitoring and control system?	3	Countermeasures
Inability to Adequately Process Solid Wastes (Risk No. 5)	1.31	What is the best method to process solid wastes for storage and/or disposal?	2	Countermeasures
	1.32	What is the best method to process solid wastes to recover resources?	2	Countermeasures
	1.33	What constraints should be imposed on materials such as packaging, paper, etc.?	3	Countermeasures
	1.34	How should solid waste streams be separated (edible plant biomass, trash and paper, feces, etc.)?	3	Countermeasures
	1.35	What is the best methodology for dealing with residuals?	2	Countermeasures
	1.36	Are sensors available to monitor performance?	3	Countermeasures
	1.37	What is the best monitoring and control system?	3	Countermeasures
Inadequate Stowage and Disposal Facilities for Solid and Liquid Trash Generated During Mission (Risk No. 6)	1.44	Could any of the solid waste be recycled in such a way to provide building material for habitability features needed in subsequent phases of the mission?	3	Countermeasures

6.1 Advanced Life Support (continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Inadequate Nutrition (Malnutrition) Due to Inability to Provide and Maintain a Bioregenerative System (Risk No. 53)	1.46	What percentage of crew food needs should be attributed to ALS plant products?	1	Countermeasures
	1.47	What processing processes and hardware will be required to convert ALS plant products into edible supplements to stowed food?	1	Countermeasures
	1.15	What are the effects of radiation on plant growth?	1	Mechanisms
	1.09	What is the best method to grow plants with established plant production requirements including light, water, gas, gas composition and pressure, trace gas contaminants, nutrient status, mechanical support, freedom from diseases and insects?	2	Countermeasures
	1.10	What species and cultivars should be used to optimize production and meet nutritional requirements?	2	Mechanisms
	1.11	What mechanized or automated systems for planting, harvesting, and monitoring and control are required?	2	Countermeasures
	1.12	What methods are best to maintain genetic integrity?	2	Countermeasures
	1.14	What processing and storage of plant products must be accommodated?	2	Countermeasures
	1.13	What are the interfaces with the air revitalization and water recovery systems?	3	Countermeasures

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6.2 Bone Loss

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Acceleration of Age-Related Osteoporosis (Risk No. 9)	2.03	Will bone mass loss (e.g., 1-1.5% per month) continue unabated for missions greater than six months in duration, or will it eventually plateau at some time consistent with absolute bone mineral density? Is this "minimum BMD" site-specific or consistent over numerous skeletal sites?	1	Risk Assessment
	2.09	What are the most important predictors for bone loss during prolonged exposure to hypogravity, especially with reference to ethnicity, gender, age, baseline BMD, bone morphometry (e.g., femoral neck length)?	1	Risk Assessment
	2.19	Is bone loss reversible and within what time frame: Can geometry and architecture return to baseline as well as BMD?	1	Risk Assessment
	2.25	Can the pattern of reversibility be correlated with serum or urine biomarkers of bone turnover?	NR*	Mechanisms
	2.26	How does treatment initiation in returning crew with bone loss diminish the risk of postflight fracture by facilitating more rapid return to preflight bone status?	NR	Countermeasures
	2.20	What is the most optimal rehabilitation regimen upon return to normal gravity to maximize return to baseline BMD and bone morphometry, especially given that muscle strength will recover more quickly than will bone strength?	2	Countermeasures

*NR: Currently not rated by the discipline risk area team

6.2 Bone Loss (Continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Fracture and Impaired Fracture Healing (Risk No. 10)	2.03	Will bone mass loss (e.g., 1-1.5%) continue unabated for missions greater than six months in duration, or will it eventually plateau at some time consistent with absolute bone mineral density? Is this "minimum BMD" site-specific or consistent over numerous skeletal sites?	2	Risk Assessment
	2.01	What is the relative risk of sustaining a traumatic and/or stress fracture for a given decrement in bone mineral density or bone geometry in an astronaut-equivalent population (i.e., 30-60 year old health men and women) who are also physically active?	1	Risk Assessment
	2.09	What are the most important predictors for bone loss during prolonged exposure to hypogravity, especially with reference to ethnicity, gender, age, baseline BMD, bone morphometry (e.g., femoral neck length)?	1	Risk Assessment
	2.11	Does prolonged exposure to hypogravity lead to impaired healing fractures? What evidence supports the alteration in vertebral morphometry during and after extended spaceflight?	4	Risk Assessment
	2.24	How can animal models be used to better understand the risk of fractures and impaired fracture healing?	NR*	Mechanisms
	2.02	What are the mechanical loads imposed on important skeletal sites in the Martian environment of 1/3 g, given anticipated work tasks?	1	Mechanisms
	2.04	What localized bone changes at tendon sites would contribute to increased risk of avulsion fractures (i.e., how much disparity between bone & muscle strength can be incurred without increased risk of avulsion fracture)?	2	Mechanisms
	2.05	Is there an additive or synergistic effect of estrogen deficiency (as in post-menopausal or amenorrheic women) and prolonged exposure to hypogravity?	4	Mechanisms
	2.10	Does hypogravity exposure change the nutritional requirements for optimal bone health (e.g., does calcium absorption decrease)?	1	Mechanisms
	2.12	What are the signal transduction pathways allowing bone cells to sense gravity and loading on bone?	2	Mechanisms
	2.13	Does hypogravity affect the size, viability or differentiation of precursor bone cell populations?	2	Mechanisms
	2.15	Are there important other mechanisms for bone loss with hypogravity that are critical to developing effective countermeasures (e.g., fluid shifts with altered hydrostatic pressure, changes in blood flow, immune system alterations)?	2	Mechanisms
	2.06	What pharmacological agents will most effectively minimize the decrease in bone mass with hypogravity? Are anabolic as well as anti-resorptive agents required?	1	Countermeasures
	2.07	What are the specifics of the optimal exercise regimen to be followed during exposure to hypogravity to minimize decreases in bone mass with regard to workout duration, intensity, frequency? Is impact loading an essential element? If so, how can it be produced in hypogravity?	1	Countermeasures
	2.08	Is there an optimal combination of exercise (an anabolic stimulus) and a pharmacological countermeasure (anti-resorptive) to minimize decrements in bone mass in hypogravity?	1	Countermeasures
	2.23	What is the difference between loss of BMD and projected increase in fracture risk? Is the risk of fracture in lower extremities related to bone loss either during or after spaceflight?	NR*	Risk Assessment
	2.26	How does treatment initiation in returning crew with bone loss diminish the risk of postflight fracture by facilitating more rapid return to preflight bone status?	NR	Countermeasures
	2.14	What practical diagnostic tools can be utilized during multi-year missions to monitor and quantify changes in bone mass and strength (e.g., biochemical markers, DEXA, ultrasound)?	2	Medical Diagnosis and Treatment

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6.2 Bone Loss (Continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/CM Category ⁵
Injury to Soft Connective Tissue, Joint Cartilage, Intervertebral Disc Rupture with or without Neurological Complications (Risk No. 11)	2.17	What is the incidence of soft connective tissue injury and pain during recovery after prolonged hypogravity or bed rest? (Use pre- and postflight analyses of MRI scan of spine and extremities and postflight follow-up studies over six months to one year.)	1	Risk Assessment
	2.18	What countermeasures can reduce the incidence of soft connective tissue injury and pain during recovery after prolonged hypogravity or bed rest?	1	Countermeasures
Renal Stone Formation (Risk No. 12)	2.05	Is there an additive or synergistic effect of estrogen deficiency (as in post-menopausal or amenorrheic women) and prolonged exposure to hypogravity?	4	Mechanisms
	2.09	What are the most important predictors for bone loss during prolonged exposure to hypogravity, especially with reference to ethnicity, gender, age, baseline BMD, bone morphometry (e.g., femoral neck length)?	1	Mechanisms
	2.10	Does hypogravity exposure change the nutritional requirements for optimal bone health (e.g., does calcium absorption decrease)?	1	Mechanisms
	2.13	Does hypogravity affect the size, viability or differentiation of precursor bone cell populations?	2	Mechanisms
	2.06	What pharmacological agents will most effectively minimize the decrease in bone mass with hypogravity? Are anabolic regimes as well as anti-resorptive agents required?	1	Countermeasures
	2.07	What are the specifics of the optimal exercise regimen to be followed during exposure to hypogravity to minimize decreases in bone mass with regard to workout duration, intensity, frequency? Is impact loading an essential element? If so, how can this be produced in hypogravity?	1	Countermeasures
	2.08	Is there an optimal combination of exercise (an anabolic stimulus) and a pharmacological countermeasure (anti-resorptive) to minimize decrements in bone mass in hypogravity?	1	Countermeasures
	2.21	Does existing data allow prediction of stone risk?	NR*	Risk Assessment

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6.3 Cardiovascular Alterations

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Occurrence of Serious Cardiac Dysrhythmias (Risk No. 13)	3.01	Does spaceflight increase susceptibility to serious cardiac dysrhythmias and, if so, what are the mechanisms?	1	Risk Assessment/ Mechanisms
	3.02	Can risk of serious cardiac dysrhythmias be predicted for individual crewmembers?	1	Risk Assessment/ Mechanisms
	3.03	What countermeasures may prevent or reduce the occurrence of serious cardiac dysrhythmias during long term spaceflight?	2	Countermeasures
	3.04	Can serious cardiac dysrhythmias be effectively diagnosed and treated during spaceflight?	2	Medical Diagnosis and Treatment
Impaired Cardiovascular Response to Orthostatic Stress (Risk No. 14)	3.05	What are the physiological and environmental factors by which spaceflight decreases orthostatic tolerance?	1	Mechanisms
	3.06	How does duration of spaceflight affect the severity and time course of orthostatic intolerance, and what are the mechanisms?	1	Risk Assessment/ Mechanisms
	3.07	Is orthostatic intolerance likely to develop on the surface of Mars?	1	Risk Assessment
	3.08	Can spaceflight-induced orthostatic intolerance be predicted for individual crewmembers?	1	Risk Assessment/ Countermeasures
	3.09	What countermeasures can be developed to overcome or prevent orthostatic intolerance?	1	Countermeasures
Diminished Cardiac Function (Risk No. 15)	3.17	Does long duration spaceflight lead to diminished cardiac function and, if so, what are the mechanisms and is the process reversible?	2	Mechanisms
	3.18	What is the extent of reduction in cardiac mass associated with long duration spaceflight and what are the mechanisms?	2	Mechanisms
	3.19	Can susceptibility to reduced cardiac function be predicted for individual crewmembers?	2	Risk Assessment/ Countermeasures
	3.20	What countermeasures may be effective in mitigating the risk?	2	Countermeasures

6.3 Cardiovascular Alterations (Continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Manifestation of Previously Asymptomatic Cardiovascular Disease (Risk No. 16)	3.14	Are cardiovascular diseases likely to be aggravated by spaceflight and, if so, which ones and by what mechanisms?	1	Risk Assessment/ Mechanisms
	3.15	What improved screening methods might identify crewmembers with underlying cardiovascular disease which may be aggravated by spaceflight?	1	Countermeasures
	3.16	What countermeasures may be effective in mitigating the risk?	2	Countermeasures
Impaired Cardiovascular Response to Exercise Stress (Risk No. 17)	3.10	What are the physiological and environmental factors by which spaceflight decreases aerobic exercise capacity?	1	Mechanisms
	3.11	How does duration of spaceflight affect the severity of limitation of exercise capacity?	1	Risk Assessment
	3.12	Can aerobic exercise capacity limitation be predicted for individual crewmembers?	2	Countermeasures
	3.13	What countermeasures can be developed to overcome aerobic exercise capacity limitation?	2	Countermeasures

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6.4 Environmental Health

Risk¹	CQ No. ²	Critical Question³	CQ Priority⁴	Critical Question & Risk Mitigation/ CM Category⁵
Allergies and Hypersensitivity Reactions from Exposure to the Enclosed Spacecraft and Other Environmental Factors (Risk No. 50)	4.07	What impact do spaceflight-induced biological, physiological, & immunological changes have on the susceptibility of crewmembers to toxic substances in the air and water?	2	Mechanisms/ Countermeasures
	4.08	What are the effects of exposure to ultrafine and larger (respirable and non-respirable) particles (e.g., Martian dust) on crew health, safety and performance?	2	Risk Assessment
	4.14	How will persons who are hypersensitive to chemicals and microbes in air and water be identified?	2	Countermeasures
	4.16	If hypersensitivity develops during spaceflight, how will individuals be treated?	1	Medical Diagnosis & Treatment
Inability to Maintain Acceptable Atmosphere in Habitable Areas Due to Environmental Health Contaminants (Risk No. 51)	4.01	What are the most likely sources of severe air or water pollution and how can these sources be controlled over long periods of time?	1	Risk Assessment & Countermeasures
	4.02	What are the acceptable numbers and kinds of microorganisms in air, water, food, and surfaces?	1	Risk Assessment
	4.03	What resources are required to manage plausible environmental risks during long and remote missions?	1	Countermeasures
	4.04	How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures?	2	Risk Assessment
	4.05	What approaches to setting exposure standards may be used when insufficient data are available to allow prediction of acceptable exposure levels?	1	Risk Assessment
	4.06	How much risk do materials that condense inside the spacecraft pose to the environmental health?	2	Risk Assessment
	4.07	What impact do spaceflight-induced biological, physiological, & immunological changes have on the susceptibility of crewmembers to toxic substances in the air and water?	2	Mechanisms
	4.08	What are the effects of exposure to ultrafine and larger (respirable and non-respirable) particles (e.g., Martian dust) on crew health, safety and performance?	2	Risk Assessment
	4.11	What are the interactions of microbes, chemicals, and plants in a CELSS on air and water quality?	2	Mechanisms
	4.12	What are the effects of the space environment on microbial interactions with space systems and humans?	2	Mechanisms
	4.13	How rapidly can acceptable air quality be recovered after a severe pollution condition and what is the effect on humidity condensate and the water recovery system?	2	Countermeasures
	4.15	How can automated real-time systems be used to monitor air and water quality for a Mars mission, and how will the crew interpret results without ground support?	1	Risk Assessment / Countermeasures

6.4 Environmental Health (Continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Inability to Provide and Recover Potable Water due to Environmental Health Contaminants (Risk No. 52)	4.01	What are the most likely sources of severe air or water pollution and how can these sources be controlled over long periods of time?	1	Risk Assessment & Countermeasures
	4.02	What are the acceptable numbers and kinds of microorganisms in air, water, food, and surfaces?	1	Risk Assessment
	4.03	What resources are required to manage plausible environmental risks during long and remote missions?	1	Countermeasures
	4.04	How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures?	2	Risk Assessment
	4.05	What approaches to setting exposure standards may be used when insufficient data are available to allow prediction of acceptable exposure levels?	2	Risk Assessment
	4.07	What impact do spaceflight-induced biological, physiological, & immunological changes have on the susceptibility of crewmembers to toxic substances in the air and water?	2	Mechanisms
	4.11	What are the interactions of microbes, chemicals, and plants in a CELSS on air and water quality?	2	Mechanisms
	4.12	What are the effects of the space environment on microbial interactions with space systems and humans?	2	Mechanisms
	4.13	How rapidly can acceptable air quality be recovered after a severe pollution condition and what is the effect on humidity condensate and the water recovery system?	2	Mechanisms/ Countermeasures
	4.15	How can automated real-time systems be used to monitor air and water quality for a Mars mission, and how will the crew interpret results without ground support?	1	Countermeasures

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5.5 Food and Nutrition

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Inadequate Nutrition (Malnutrition) (Risk No. 7)	5.03	What are the nutritional requirements for exploration missions, e.g., calories, protein, calcium, iron, antioxidants, iodine, vitamin D, electrolytes?	1	Countermeasures
	5.04	What are the potential impacts of countermeasures on nutritional requirements?	1	Mechanisms
	5.05	What are the psychosocial requirements of the food system?	2	Mechanisms
	5.08	What technology will be required to develop a viable food system?	2	Countermeasures
	5.09	What type(s) of food system(s) should be used?	1	Countermeasures
	5.07	What monitoring method should be used to assure food safety during the entire mission?	2	Countermeasures
	5.10	What are the means of monitoring nutritional status during the mission?	3	Countermeasures
	5.01	How much flight access is required to answer above questions?	2	NA
	5.06	What are the sensory changes (taste, odor, etc.) that occur during spaceflight?	4	Mechanisms
	5.02	What are the impacts of changing gravity on the food system i.e., galley?	3	Mechanisms
Unsafe Food Systems (Risk No. 8)	5.13	What are the effects of extended space travel on the sensory and nutrient properties of food?	2	Mechanisms
	5.08	What technology will be required to develop a viable food system?	1	Countermeasures
	5.09	What type(s) of food system(s) should be used?	1	Countermeasures
	5.07	What monitoring method should be used to assure food safety during the entire mission?	2	Countermeasures
	5.02	What are the impacts of changing gravity on the food system i.e., galley?	3	Mechanisms / Processes

6.5 Food and Nutrition (Continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Unsafe Food Systems (Risk No. 8)	5.11	What type of packaging is required?	1	Countermeasures
	5.12	What is the risk of chemical and microbial contamination?	1	Risk Assessment
	5.01	How much flight access is required to answer above questions?	4	NA
Human Performance Failure Due to Nutritional Deficiencies (Risk No. 55)	5.03	What are the nutritional requirements for exploration missions (e.g., calories, protein, calcium, iron, antioxidants, iodine, vitamin D, electrolytes)?	1	Countermeasures
	5.14	What is an acceptable food system?	2	Countermeasures
	5.01	How much flight access is required to answer above questions?	3	NA
	5.05	What are the psychosocial requirements of the food system?	2	Mechanisms/ Processes / Countermeasures
Difficulty of Rehabilitation Following Landing Due to Nutritional Deficiencies (Risk No. 54)	5.03	What are the nutritional requirements for exploration missions, e.g. calories, protein, calcium, iron, antioxidants, iodine, vitamin D, electrolytes?	1	Countermeasures
	5.15	What are the decrements in nutritional status due to long term spaceflight?	1	Risk Assessment
	5.16	What monitoring (biochemical, anthropometric, clinical assessments) during rehabilitation is required?	3	Medical Diagnosis and Treatment
	5.17	What level of dietary counseling is needed for crewmembers during rehabilitation?	3	Countermeasures
	5.18	Are there inflight countermeasures that affect nutritional status (promote or cause decrements)?	2	Countermeasures

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6.6 Human Behavior and Performance

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/CM Category ⁵
Human Performance Failure Because of Poor Psychosocial Adaptation (Risk No. 18)	6.01	What are the fundamental behavioral and social stressors during long duration missions that will most likely affect crew performance, both individual and team?	1	Risk Assessment
	6.02	What model(s) of psychological adaptation in isolated and confined environments will best predict the effect on individual and team performance over the course of the mission, and what tools can best monitor these models?	2	Risk Assessment
	6.03	What behaviors, experiences, personality traits, and leadership styles in crewmembers most contribute to optimal performance? How are these factors related to team performance?	2	Mechanisms/Processes
	6.04	What crewmember behaviors, experiences, personality traits, and leadership styles that optimize performance can be identified during the selection process and be used to select and assemble the best teams for long duration missions?	2	Countermeasures
	6.17	What are the systems of knowledge, psychosocial support methods, attitudes, and behavior towards mission operations used by agency management, ground controllers, crewmembers and their families? How do these systems influence individual and group performance and behavior?	2	Countermeasures
Human Behavior Failure Because of Sleep and Circadian Rhythm Problems (Risk No. 19)	6.05	What are the acute and long term effects of exposure to the space environment on biological rhythmicity on sleep architecture, quality and quantity, and their relationship to performance capability?	1	Mechanisms/Processes
	6.06	Which countermeasure or combination of behavioral and physiological countermeasures will optimally mitigate specific performance problems associated with sleep loss and circadian disturbances during a Mars mission?	1	Countermeasures
	6.07	What are the long term effects of countermeasures employed to mitigate performance problems with sleep loss and circadian disturbances during a Mars mission?	2	Mechanisms/Processes
	6.08	What are the best methods of inflight monitoring the status of sleep and circadian functioning and for assessing the effects of sleep loss and circadian dysrhythmia on performance capability that are also portable and non-intrusive in the spaceflight environment?	2	Medical Diagnosis & Treatment
	6.10	What workload schedule(s) per workday will best enhance crew performance and mitigate adverse effects of the space environment?	2	Countermeasures
	6.21	What mathematical and experimental models best predict performance problems associated with sleep-wake and work history and circadian rhythm status, and also provide guidelines for successful countermeasure strategies?	2	Countermeasures
	6.18	What individual and behavioral characteristics will best predict successful adaptation to long term spaceflight of sleep and circadian physiology and the neurobehavioral performance functions they regulate?	NR*	Risk Assessment/ Mechanisms/Processes

6.6 Human Behavior and Performance

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & CM Category ⁵
Human Performance Failure Because of Human System Interface Problems and Ineffective Habitat, Equipment Design, Workload, or Inflight Information and Training Systems (Risk No. 20)	6.09	What information management and communications systems architecture(s) and equipment will best support the crew's ability to exchange information, learn and maintain proficiency on critical tasks, and meet the objectives of a Mars mission? How will artificial intelligence or expert systems be used in these architectures?	1	Countermeasures
	6.10	What workload schedule(s) per workday will best enhance crew performance and mitigate adverse effects of the space environment?	2	Countermeasures
	6.11	What methods of assessing human performance capabilities will be most effective and useable during a Mars mission?	2	Medical Diagnosis & Treatment
	6.12	What factors in systems and habitat design will best enhance the crew's ability to live and work in the space environment? How are these factors different from shorter duration missions?	2	Mechanisms/Processes
Human Performance Failure Because of Neurobehavioral Dysfunction (Risk No. 21)	6.13	What model(s) of behavioral health and task performance best predict problems and provide guidelines for effective treatment of illness (e.g., Depression, Anxiety, Trauma, Psychiatric Dysfunction)?	1	Risk Assessment
	6.14	What are the best countermeasures for rapidly recognizing and rapidly managing neurobehavioral dysfunction, emotional and stress-related dysfunction, neuropsychiatric dysfunction, and social psychological dysfunction and how does the spaceflight environment affect their implementation?	1	Countermeasures
	6.15	What are the acute and long term effects of exposure to the space environment on the human cognition and performance capabilities, including processes of sensation and perception, learning, vigilance, cognition, problem-solving, decision making, and motor skills, and how do such changes affect human performance capabilities and behavior?	2	Mechanisms/Processes
	6.16	What are the acute and long term effects of exposure to the space environment (microgravity, isolation, stress) on the nervous system (at the cellular, molecular, or organismic levels) and on related neurobehavioral mechanisms, including neurobiology related to behavior and mood regulation?	2	Mechanisms/Processes
	6.19	What are the acute and long term effects of exposure to the space environment on human emotion and psychological responses, including emotional reactivity, stress responses, long term modulation of mood, and vulnerability to affective disorders?	NR*	Mechanisms/Processes
	6.20	What are the best methods of inflight monitoring for neurobehavioral dysfunction, including cognitive and performance dysfunction, emotional and stress-related dysfunction, neuropsychiatric dysfunction, and social psychological dysfunction?	NR	Medical Diagnosis & Treatment

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6.7 Immunology, Infection and Hematology

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Immunodeficiency/ Infections (Risk No. 22)	7.17	Which potentially infectious agents will crewmembers be exposed to and what are their sources?	2	Risk Assessment
	7.01	Are there assays of immune function that reliably predict immune compromise?	2	Risk Assessment
	7.29	Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function?	NR*	Risk Assessment / Medical Diagnosis & Treatment
	7.27	Can medical records of astronauts be obtained for epidemiological study of long term adverse health consequences of space travel (e.g., immunodeficiency, chronic viral infections, malignancy, hypersensitivity and allergy)?	NR	Risk Assessment
	7.22	Are there countermeasures for spaceflight-associated defects in antibody, T-cell, phagocyte, and complement systems?	NR	Countermeasures
	7.23	Are there countermeasures for infections developed in space travel, especially latent virus infections?	NR	Countermeasures
	7.13	What diagnostic and environmental monitoring laboratory technologies need to be developed for the detection and diagnosis of infectious disease in microgravity?	3	Medical Diagnosis and Treatment
	7.10	Does the change in fluid distribution away from the extremities affect microcirculation in peripheral tissues, and does this represent a risk to the crew (wound healing, lymphocyte migration, immune surveillance)?	1	Risk Assessment / Mechanisms
	7.03	Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, non-specific immunity, mucosal immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)?	1	Risk Assessment / Mechanisms
	7.11	Does the spacecraft environment exert a selective pressure on environmental microorganisms which presents the crew with increased health risks (e.g. heliobacteria and ulcers)?	2	Risk Assessment
	7.04	Do factors associated with spaceflight increase activation of latent viruses?	2	Risk Assessment / Mechanisms
	7.20	Does the loss of blood volume in spaceflight affect immune surveillance?	2	Risk Assessment / Mechanisms
	7.21	Does the alteration of sleep wake cycles produce alterations in chronobiology of immune responses due to upsetting the neuroendocrine axis and producing stress?	NR	Mechanisms
	7.25	Are there deficiencies of diet or micronutrients in long term space travel that would negatively impact on the CD4 ⁺ T-Cell population and produce immunosuppression?	NR	Mechanisms
	7.26	Are there diet supplements or additives that could restore a malnutrition-induced state of immunosuppression?	NR	Countermeasures
	7.28	Do conditions of mechanical forces of space travel disrupt cytokine: cytokine receptor signal transmissions in immune cells?	NR	Mechanisms

6.7 Immunology, Infection and Hematology (Continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Carcinogenesis Caused by Immune System Changes (Risk No. 23)	7.14	What is the risk of cancer during or following long duration spaceflight?	1	Risk Assessment
	7.01	Are there assays of immune function that reliably predict immune compromise?	2	Risk Assessment
	7.29	Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function?	NR*	Risk Assessment
	7.24	Are there countermeasures for development of malignancy in space travel?	NR	Countermeasures
	7.18	What diagnostic and treatment capabilities are required for radiation induced illness?	3	Medical Diagnosis and Treatment
	7.30	Does the change in fluid distribution affect microcirculation in peripheral tissues, and does this alter lymphocyte migration or immune surveillance?	2	Mechanisms
	7.03	Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)?	1	Mechanisms
	7.04	Do factors associated with spaceflight increase reactivation of latent tumor viruses?	2	Mechanisms
	7.15	Which oncogenic mechanisms may be activated by in-flight radiation exposure?	2	Mechanisms
	7.21	Does the alteration of sleep wake cycles produce alterations in chronobiology of immune responses due to upsetting the neuroendocrine axis and producing stress?	NR	Mechanisms

6.7 Immunology, Infection and Hematology (Continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Altered Hemodynamic and Cardiovascular Dynamics Caused by Alterations in Blood Components (Risk No. 24)	7.12	Does the anemia following spaceflight diminish the aerobic capacity of individuals entering a gravitational environment or represent a risk to crewmembers on landing?	2	Risk Assessment
	7.03	Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, non-specific immunity, mucosal immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)?	1	Risk Assessment
	7.31	Does the change in fluid distribution away from the extremities affect microcirculation in peripheral tissues, and does this represent a cardiovascular, muscle, or bone risk to the crew?	1	Mechanisms
	7.20	Does the loss of blood volume in spaceflight affect immune surveillance?	1	Mechanisms
	7.02	Can the physiologic mechanisms responsible for hematopoiesis be influenced to increase red cell mass?	NR	Mechanisms, Countermeasures
	7.29	Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function?	NR	Medical Diagnosis and Treatment
Altered Wound Healing (Risk No. 25)	7.01	Are there assays of immune function that reliably predict immune compromise?	2	Risk Assessment
	7.29	Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function?	NR	Risk Assessment, Medical Diagnosis & Treatment
	7.16	Which compounds can be used as effective promoters of wound healing?	3	Countermeasures
	7.32	Does the change in fluid distribution away from the extremities affect microcirculation in peripheral tissues, and does this represent a risk to the crew (wound healing, lymphocyte migration, immune surveillance)?	2	Risk Assessment / Mechanisms
	7.03	Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)?	1	Risk Assessment / Mechanisms

6.7 Immunology, Infection and Hematology (Continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Altered Host-Microbial Interactions (Risk No. 26)	7.06	Does spaceflight alter microbial growth rates, mutation rates, or pathogenicity?	2	Risk Assessment, Mechanisms
	7.11	Does the spacecraft environment exert a selective pressure on environmental microorganisms which presents the crew with increased health risks (e.g., heliobacteria and ulcers)?	2	Risk Assessment, Mechanisms
	7.09	Does spaceflight alter the exchange of genetic material between microorganisms?	2	Mechanisms
	7.19	Does spaceflight alter host-microbe balance?	2	Mechanisms
	7.23	Are there countermeasures for infections developed in space travel, especially latent-virus infections?	NR*	Countermeasures
	7.13	What diagnostic and environmental monitoring laboratory technologies need to be developed for the detection and diagnosis of infections in microgravity?	3	Medical Diagnosis and Treatment
Allergies and Hypersensitivity Reactions (Risk No. 27)	7.01	Are there assays of immune function that reliably predict immune compromise?	3	Risk Assessment
	7.03	Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)?	1	Risk Assessment, Mechanisms
	7.05	Do unique environmental factors inside the spacecraft promote transmission of microbial pathogens, or cause increased risk of infection, allergy or hypersensitivity reactions independent of altered immune function?	2	Mechanisms
	7.23	Are there countermeasures for infections developed in space travel, especially latent-virus infections?	NR	Countermeasures
	7.29	Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function?	NR	Medical Diagnosis and Treatment

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6.8 Muscle Alterations and Atrophy

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Loss of Skeletal Muscle Mass, Strength, and/or Endurance (Risk No. 28)	8.03	What is the role of, and what is necessary in order to establish the hormonal profile of astronauts during long duration spaceflight?	1	Mechanisms
	8.09	How do muscle cells sense the mechanical stress of gravity?	1	Mechanisms
	8.01	What are the appropriate prescription modalities and the compliance factors needed to minimize losses in muscle mass, strength and endurance, and facilitate rehabilitation?	1	Countermeasures
	8.02	To what extent should hormonal/pharmacological supplements be used as a countermeasure if exercise regimens are ineffective in maintaining homeostasis?	1	Countermeasures
	8.08	What are the appropriate exercise modalities and prescriptions needed to optimize skeletal muscle performance?	1	Medical Diagnosis & Treatment
Inability to Adequately Perform Tasks Due to Motor Performance, Muscle Endurance, and Disruptions in Structural and Functional Properties of Soft and Hard Connective Tissues of the Axial Skeleton (Risk No. 29)	8.03	What is the role of, and what is necessary in order to establish the hormonal profile of astronauts during long duration spaceflight?	1	Mechanisms
	8.01	What are the appropriate prescription modalities and the compliance factors needed to minimize losses in muscle mass, strength and endurance, and facilitate rehabilitation?	1	Countermeasures
	8.02	To what extent should hormonal/pharmacological supplements be used as a countermeasure if exercise regimens are ineffective in maintaining homeostasis?	1	Countermeasures
	8.08	What are the appropriate exercise modalities and prescriptions needed to optimize skeletal muscle performance?	1	Medical Diagnosis & Treatment

6.8 Muscle Alterations and Atrophy

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Inability to Sustain Muscle Performance Levels to Meet Demands of Performing Activities of Varying Intensities (Risk No. 30)	8.04	What effect does long term spaceflight/operational countermeasure has on nitrogen balance (i.e., anabolic/catabolic control of protein expression)?	1	Mechanisms/ Countermeasures
	8.05	What are the effects of long term spaceflight on the metabolism of carbohydrates and fats, and what is their influence on sustained aerobic work and performance?	1	Mechanisms
Propensity to Develop Muscle Injury, Connective Tissue Dysfunction, and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength and Muscular Fatigue (Risk No. 31)	8.06	Do the deficits in skeletal muscle associated with long duration spaceflight affect the structural/functional properties of the sensory system and motor nerves? Describe the changes in muscle tendon interface.	1	Mechanisms
	8.07	Do structural & functional deficits in skeletal muscle system associated with long duration spaceflight impact: neurovestibular homeostasis; cardiovascular deconditioning; deficits in bone (regional & general); the muscle and tendon interface, and feedback from skeletal muscle to CNS (hypothalamus, hypophysis)?	1	Mechanisms
Impact of Deficits in Skeletal Muscle Structure and Function on Other Systems (Risk No. 32)	8.06	Do the deficits in skeletal muscle associated with long duration spaceflight affect the structural/functional properties of the sensory system and motor nerves? Describe the changes in the muscle tendon interface.	1	Mechanisms
	8.07	Do structural & functional deficits in skeletal muscle system associated with long duration spaceflight impact: neurovestibular homeostasis; cardiovascular deconditioning; deficits in bone (regional & general); the muscle and tendon interface, and feedback from skeletal muscle to CNS (hypothalamus, hypophysis)?	1	Mechanisms

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6.9 Neurovestibular Adaptation

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Disorientation and Inability to Perform Landing, Egress, or Other Physical Tasks, Especially During/After G-Level Changes (Acute spontaneous & provoked vertigo, nystagmus, oscillopsia, poor dynamic visual acuity) (Risk No. 33)	9.02	What are the appropriate ground-based spaceflight analog environments that can be used as test beds for evaluating neurological adaptation time constants, adverse operational implications, countermeasures, and impacts of adaptation on other anatomical and physiological systems?	2	Risk Assessment/ Mechanisms/ Countermeasures
	9.03	How do altered time constants associated with neurological (sensorimotor, autonomic, emetic) adaptation to spaceflight (microgravity and 1/3 Mars surface) correlate with physiological and operational performance changes?	3	Risk Assessment
	9.05	How do the large inter-individual differences in response to altered magnitude and duration of gravito-inertial forces (weightlessness and return to Earth) correlate with physiological and operational performance changes?	3	Risk Assessment/ Mechanisms
	9.09	What is the physiological basis of inversion illusions, visual reorientation, and 3D memory problems in 0-G?	2	Mechanisms
	9.25	What is the physiological basis for oscillopsia, disorientation, and reduced dynamic visual acuity reported by crewmembers making head movements during re-entry?	2	Mechanisms
	9.01	What are the pros and cons of artificial gravity (AG) as a countermeasure? What are the advantages and disadvantages of large radius continuous AG vs. short radius, intermittent AG?	1	Countermeasures
	9.04	How do countermeasures (e.g., artificial gravity, inflight exercise, or preflight training) affect adaptation time constants?	3	Countermeasures
	9.08	How do visual, vestibular and haptic cues contribute to inversion illusions, visual reorientation, illusions, EVA acrophobia, disorientation and poor 3D spatial memory problems in 0-G?	2	Countermeasures
	9.10	Can preflight training techniques (e.g., virtual reality simulations) be used to alleviate these problems, and to evaluate emergency procedures?	2	Countermeasures
	9.27	How can 0-G immersive teleoperation displays be designed to reduce disorientation and/or motion sickness?	2	Countermeasures

6.9 Neurovestibular Adaptation (Continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Impaired Neuromuscular Coordination and/or Strength (Gait ataxia, postural instability) (Risk No. 34)	9.02	What are the appropriate ground-based spaceflight analog environments that can be used as test beds for evaluating neurological adaptation time constants, adverse operational implications, countermeasures, and impacts of adaptation on other anatomical and physiological systems?	2	Risk Assessment/ Mechanisms/ Countermeasures
	9.05	How do the large inter-individual differences in response to altered magnitude and duration of gravito-inertial forces (weightlessness and return to Earth) correlate with physiological and operational performance changes?	3	Risk Assessment/ Mechanisms
	9.22	What is the relative contribution of neurovestibular adaptation, neuromuscular deconditioning, and orthostatic intolerance to postflight neuromuscular coordination, ataxia and locomotion difficulties?	2	Risk Assessment/ Mechanisms
	9.01	What are the pros and cons of artificial gravity (AG) as a countermeasure? What are the advantages and disadvantages of large radius continuous AG vs. short radius, intermittent AG?	1	Countermeasures
	9.04	How do countermeasures (e.g., artificial gravity, in-flight exercise, or preflight training) affect adaptation time constants?	3	Countermeasures
	9.24	Can preflight or in-flight training, or sensory aids and prostheses, improve postlanding postural and locomotor control?	2	Countermeasures

6.9 Neurovestibular Adaptation

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Impaired Cognitive and/or Physical Performance Due to Motion Sickness Symptoms or Treatments, Especially During/After G-level Changes (Including short term memory loss, reaction time increase, drowsiness, fatigue, torpor, irritability, ketosis) (Risk No. 35)	9.11	What physical and cognitive performance will be required of the crew during the acceleration/deceleration portions of the mission?	2	Risk Assessment
	9.26	What is the physiological basis of space motion sickness? How does chronic space motion sickness (including sopite syndrome) affect mood, initiative, and interpersonal relationships?	2	Mechanisms
	9.12	How effective is promethazine injection (or other drugs) in providing fast relief in mission critical situations? Does the drug have unacceptable side effects, particularly the short term effects on cognitive function?	1	Countermeasures
	9.23	To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness?	2	Countermeasures
	9.27	How can 0-G immersive teleoperation displays be designed to reduce disorientation and/or motion sickness?	2	Countermeasures

6.9 Neurovestibular Adaptation (Continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Vestibular Contribution to Cardiorespiratory Dysfunction (Postlanding orthostatic intolerance, sleep and mood changes) (Risk No. 36)	9.22	What is the relative contribution of neurovestibular adaptation, neuromuscular deconditioning, and orthostatic intolerance to postflight neuromuscular coordination, ataxia and locomotion difficulties?	2	Risk Assessment / Mechanisms / Countermeasures
	9.15	Does neurovestibular adaptation to weightlessness impair postlanding cardiovascular regulation and contribute to orthostatic intolerance?	1	Mechanisms
	9.17	How does neurovestibular adaptation contribute to postlanding postural control and locomotion difficulties?	2	Mechanisms
	9.16	Do vestibular countermeasures improve postlanding cardiovascular regulation and orthostatic tolerance?	1	Countermeasures
	9.23	To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness?	2	Countermeasures
Possible Chronic Impairment of Orientation or Balance Function Due to Microgravity or Radiation (Imbalance, gait ataxia, vertigo, chronic vestibular insufficiency, poor dynamic visual acuity) (Risk No. 37)	9.20	What are the significant irreversible changes in sensory-motor neurological function associated physiological systems, and anatomical and/or biochemical processes that may be caused by exposure or development in long duration 0-G or partial-G, and what are the mechanisms and time course?	4	Mechanisms
	9.21	How can these changes be optimally distinguished from the normal responses to stress, isolation, and normal background physiological variability? What countermeasures can be developed?	4	Countermeasures
	9.24	Can preflight or inflight training, or sensory aids and prostheses, improve postlanding postural and locomotor control?	2	Countermeasures

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6.10 Radiation Effects

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Carcinogenesis Caused by Radiation (Risk No. 38)	10.09	What are the cancer risks in humans from spaceflight?	1	Risk Assessment
	10.11	What is the acceptable accuracy for risks of acute and late effects in humans from photons to adequately extrapolate to space?	1	Risk Assessment
	10.05	Are there unique biological effects associated with HZE's?	1	Mechanisms
	10.07	How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation?	1	Mechanisms
	10.10	What are the risks from SPE's and what is their impact on operations, EVAs and surface exploration?	1	Risk Assessment
	10.08	How do the thickness, design, and material composition of space vehicles affect the internal radiation environment and biological assessment?	1	Countermeasures
	10.06	Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties?	2	Countermeasures
	10.04	Are there differences in response to particles with similar LET, but with different atomic numbers and energies?	2	Mechanisms
	10.12	What are the effects of age, gender, and inter-individual diversity?	2	Mechanisms
	10.01	Are the biological effects for protons above 10 MeV sufficiently similar to photons that photon data can be used for their consequences?	3	Mechanisms
	10.03	Are there chemopreventive or biological agents which would mitigate acute or late effects?	3	Countermeasures

6.10 Radiation Effects (Continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Damage to Central Nervous System From Radiation Exposure (Risk No. 39)	10.05	Are there unique biological effects associated with HZE's?	1	Risk Assessment
	10.07	How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation?	1	Risk Assessment
	10.10	What are the risks from SPE's and what is their impact on operations, EVAs and surface exploration?	1	Risk Assessment
	10.08	How do the thickness, design, and material composition of space vehicles affect the internal radiation environment and biological assessment?	1	Countermeasures
	10.11	What is the acceptable accuracy for risks of acute and late effects in humans from photons to adequately extrapolate to space?	2	Risk Assessment
	10.04	Are there differences in response to particles with similar LET, but with different atomic numbers and energies?	2	Mechanisms
	10.12	What are the effects of age, gender, and inter-individual diversity?	2	Mechanisms
	10.06	Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties?	3	Risk Assessment
	10.01	Are the biological effects for protons above 10 MeV sufficiently similar to photons that photon data can be used for their consequences?	3	Mechanisms
	10.03	Are there chemopreventive or biological agents which would mitigate acute or late effects?	3	Countermeasures
Synergistic Effects from Exposure to Radiation, Microgravity, and Other Spacecraft Environmental Factors (Risk No. 40)	10.09	What are the cancer risks in humans from spaceflight?	1	Risk Assessment
	10.02	Are there adverse synergisms between radiation and other space environmental and biological factors?	1	Mechanisms
	10.07	How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation?	1	Risk Assessment
	10.05	Are there unique biological effects associated with HZE's?	2	Mechanisms
	10.06	Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties?	2	Countermeasures
	10.12	What are the effects of age, gender, and inter-individual diversity?	2	Mechanisms
	10.03	Are there chemopreventive or biological agents which would mitigate acute or late effects?	3	Countermeasures

6.10 Radiation Effects

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Early or Acute Effects from Radiation Exposure (Risk No. 41)	10.11	What is the acceptable accuracy for risks of acute and late effects in humans from photons to adequately extrapolate to space?	1	Risk Assessment
	10.07	How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation?	1	Risk Assessment
	10.10	What are the risks from SPE's and what is their impact on operations, EVAs and surface exploration?	1	Risk Assessment
	10.08	How do the thickness, design, and material composition of space vehicles affect the internal radiation environment and biological assessment?	1	Countermeasures
	10.05	Are there unique biological effects associated with HZE's?	2	Mechanisms
	10.06	Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties?	2	Risk Assessment
	10.12	What are the effects of age, gender, and inter-individual diversity?	2	Mechanisms
	10.04	Are there differences in response to particles with similar LET, but with different atomic numbers and energies?	2	Risk Assessment
	10.01	Are the biological effects for protons above 10 MeV sufficiently similar to photons that photon data can be used for their consequences?	3	Mechanisms
	10.03	Are there chemopreventive or biological agents which would mitigate acute or late effects?	3	Countermeasures
Radiation Effects on Fertility, Sterility and Heredity (Risk No. 42)	10.12	What are the effects of age, gender, and inter-individual diversity?	3	Mechanisms
	10.13	What are the risks associated with fertility, sterility, and hereditary effects as a result of exposure to radiation on long duration missions?	3	Mechanisms

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6.11 Clinical Capabilities

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Trauma and Acute Medical Problems (Risk No. 43)	11.01	What are the essential technologies, resources, procedures, skills and training necessary to provide effective advanced life support (CPR, ACLS, ATLS) in space?	1	Medical Diagnosis and Treatment
	11.02	What acute and chronic diagnostic and monitoring capabilities (hardware, software, communication and data management capabilities, "smart" systems, and training) is necessary to support acute trauma, surgical and medical intervention in space?	1	Medical Diagnosis and Treatment
	11.03	What medical imaging and telemedicine (including medical informatics) capabilities (technology, skills and training) are necessary to support space medicine?	1	Medical Diagnosis and Treatment
	11.04	What are the specific techniques, resources, protocols, skills and equipment (technology) necessary to perform surgical intervention and care in the space environment (including options and techniques for anesthesia)?	2	Medical Diagnosis and Treatment
	11.05	What are effective methods and technologies for fluid (IV and other) resuscitation and transfusion in space (including blood replacement products)?	2	Medical Diagnosis and Treatment
	11.06	What are the optimal treatment methods, technologies, and protocols for the on-orbit management of acute musculoskeletal injuries (including sprains, strains, contusions and fractures)?	2	Countermeasures / Medical Diagnosis and Treatment
	11.07	What are the most effective options, protocols, and technologies to support patient transport and return to Earth definitive medical care facility?	2	Medical Diagnosis and Treatment
	11.08	What are the optimal technologies for supporting an autonomous acute medical response capability in space, including medical informatics, smart medical care systems, on orbit skills maintenance and training?	1	Medical Diagnosis and Treatment
	11.09	What are the procedures and protocols for pronouncement of death in space and for the management of a cadaver?	3	Medical Diagnosis and Treatment
	11.10	What are the essential technologies, resources, skills, and training necessary to effectively diagnose, treat, and recover patients from likely acute medical emergencies in space including, but not limited to: wounds, lacerations, and burns; toxic exposure and acute anaphylaxis; acute radiation illness; dental emergencies; ophthalmologic emergencies; gynecologic and urology emergencies; psychiatric emergencies	1	Medical Diagnosis and Treatment
	11.11	What are the technologies, methods, resources, and skills necessary to accomplish chronic care and recovery following an acute medical or surgical event in space?	1	Medical Diagnosis and Treatment
	11.12	What technologies are feasible and should be developed to support non-invasive or minimally invasive medical diagnosis and intervention capabilities in space?	1	Medical Diagnosis and Treatment

6.11 Clinical Capabilities

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Toxic Exposure (Risk No. 44)	11.13	What diagnostic, monitoring and treatment capabilities are essential for management of toxic exposure (acute and chronic)?	1	Medical Diagnosis and Treatment
	11.14	What crew screening and selection criteria should be developed and implemented to identify individuals who are at increased risk for developing hypersensitivity or allergies to spaceflight compounds, exposures, or payloads?	2	Risk Assessment and Countermeasures
	11.15	What countermeasures should be developed and implemented to prevent adverse reactions to toxic exposures (e.g. sleep, nutritional, medications, stress reduction, shielding, protective equipment, etc.)?	2	Countermeasures
Altered Pharmacodynamics and Adverse Drug Reactions (Risk No. 45)	11.16	What are the effects and implications of spaceflight alterations in human physiology on the absorption, distribution, metabolism, clearance, excretion, clinical efficacy, side effects and drug interactions for clinically useful medications?	2	Mechanisms
	11.17	What technologies are available to provide extended shelf-life pharmaceuticals for long duration spaceflight?	1	Countermeasures
	11.18	What are the side effect and interaction profiles of the commonly use medications in spaceflight, and how should the crew and medical team be trained and prepared to recognize and deal with these issues?	2	Mechanisms / Medical Diagnosis and Treatment
	11.19	What are the most appropriate dosages and routes of administration for the spaceflight clinically useful medications (taking into consideration the answers to CQ 11.16)?	1	Mechanisms / Medical Diagnosis and Treatment
	11.20	What diagnostic and laboratory technologies are necessary to predict and manage medication side effects, interactions, and toxicity during spaceflight?	1	Risk Assessment and Acceptability / Medical Diagnosis and Treatment
	11.21	What is the effectiveness, indications and risks, and proper utilization of popular non-traditional herbal and nutritional supplements and other alternative therapies (such as homeopathy, etc.)?	3	Mechanisms

6.11 Clinical Capabilities (Continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Illness and Ambulatory Health Problems (Risk No. 46)	11.22	What are the methods, technologies, and standards for conducting a nominal health and fitness examination in space (including interval history and physical, baseline diagnostics, and data management)?	1	Medical Diagnosis and Treatment
	11.23	What are the clinical norms for metabolic and physiologic variables in the space-adapted individual (including clinical laboratory and imaging norms)?	1	Medical Diagnosis and Treatment
	11.24	What are the signs, symptoms or abnormal examination findings (Including laboratory) associated with diseases observed in space?	1	Medical Diagnosis and Treatment
	11.25	What is the risk and incidence of illness and injury associated with spaceflight?	1	Risk Assessment
	11.26	What are the essential technologies, methods, resources, skills and training necessary to support physical examination, diagnosis, monitoring and treatment of illnesses and ambulatory health problems in space (including telemedicine, medical informatics, and smart medical systems)?	2	Medical Diagnosis and Treatment
	11.27	What are the technologies, procedures, and resources necessary for management of medical waste products during space?	2	Countermeasures
	11.28	What are the impacts from and issues related to communication delay on spaceflight health care and telemedicine, and what are the technologies, protocols, and skills necessary for an autonomous health care capability in space as a result of communication delay?	1	Countermeasures
	11.29	What are the provisions, technologies, methods and skills necessary to support environmental health-related diagnosis and monitoring including microbiological, toxicological, noise and radiation issues?	1	Medical Diagnosis and Treatment
	11.30	What are the optimal protocols, technologies, resources, skills and training necessary to diagnose, monitor, treat and recover patients in space from the expected illnesses and ambulatory medical problems, including but not limited to: orthopedic and musculoskeletal problems; infectious, hematological and immune-related diseases; dermatological, ophthalmologic, and ENT problems; nutritional, metabolic, and endocrine disorders; dental problems; gastrointestinal and urologic disorders; and behavioral, fatigue and stress-related problems?	1	Countermeasures Medical Diagnosis and Treatment
	11.31	What technologies can be developed and implemented to provide computer-assisted, "smart" modeling of the human system in space that can be used for individual patient modeling, monitoring, diagnosis, and prevention (predictive modeling)?	1	Countermeasures / Medical Diagnosis and Treatment
	11.32	What are alternative approaches to traditional medicine that have potential merit and should be investigated as potential adjunctive therapy for space medicine (such as biofeedback, massage therapy, musculoskeletal manipulation, acupuncture, magnet therapy)?	3	Countermeasures

6.11 Clinical Capabilities (Continued)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Development and Treatment of Space-Related Decompression Sickness (Risk No. 47)	11.33	What are the essential technologies, resources, protocols, skills and training necessary for the diagnosis, monitoring, treatment and recovery of space-related decompression sickness?	1	Countermeasures / Medical Diagnosis and Treatment
	11.35	What are the diagnostic and monitoring technologies and protocols that will provide effective screening and diagnosis of different levels and categories of decompression illness? What portable diagnostic tool can differentiate between Type I decompression sickness and stress fracture and in instances of localized bone or joint pain?	1	Medical Diagnosis and Treatment
	11.34	What is the feasibility and development pathway necessary to provide portable hyperbaric treatment capability in space?	3	Countermeasures / Medical Diagnosis and Treatment
Difficulty of Rehabilitation Following Landing (Risk No. 48)	11.36	What are the expected effects and risks of long duration spaceflight related to landing, egress and post-landing performance (in various anticipated gravitational environments)?	1	Mechanisms
	11.39	What are the issues related to and resources required for long term rehabilitation and recovery from long duration spaceflight?	2	Medical Diagnosis and Treatment
	11.38	What pre-landing and pre-egress performance and health parameters should be monitored to assure adequate cardiovascular tone, neurological function, skeletal integrity, muscular strength, and endurance?	2	Medical Diagnosis and Treatment
	11.37	What are the essential technologies, resources, protocols, skills and training necessary for post-landing performance, recovery and rehabilitation (including psychological, cardiovascular, neurosensory, musculoskeletal, and nutritional)?	1	Countermeasures / Medical Diagnosis and Treatment

¹ Risk – Title of risk and assigned risk identification number

² CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential number for the questions addressing the risk

³ Critical Question: The statement of the critical question

⁴ Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

⁵ Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment./acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

*NR: Currently not rated by the discipline risk area team

6.12 Multisystem (Cross Risk) Alterations)

Risk ¹	CQ No. ²	Critical Question ³	CQ Priority ⁴	Critical Question & Risk Mitigation/ CM Category ⁵
Postlanding Alterations in Various Systems Resulting in Performance Decrements and Injuries (Risk No. 49)	12.01	How do alterations in cardiovascular function associated with spaceflight affect the functioning of other systems?	2	Mechanisms
	12.02	How do alterations in neural, endocrine, and metabolic function associated with spaceflight affect cardiovascular functioning and the functioning of other organ systems?	2	Mechanisms
	12.03	What rehabilitative measures should be applied after mission completion?	2	Countermeasures

¹ Risk – Title of risk and assigned risk identification number

² CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential number for the questions addressing the risk

³ Critical Question: The statement of the critical question

⁴ Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

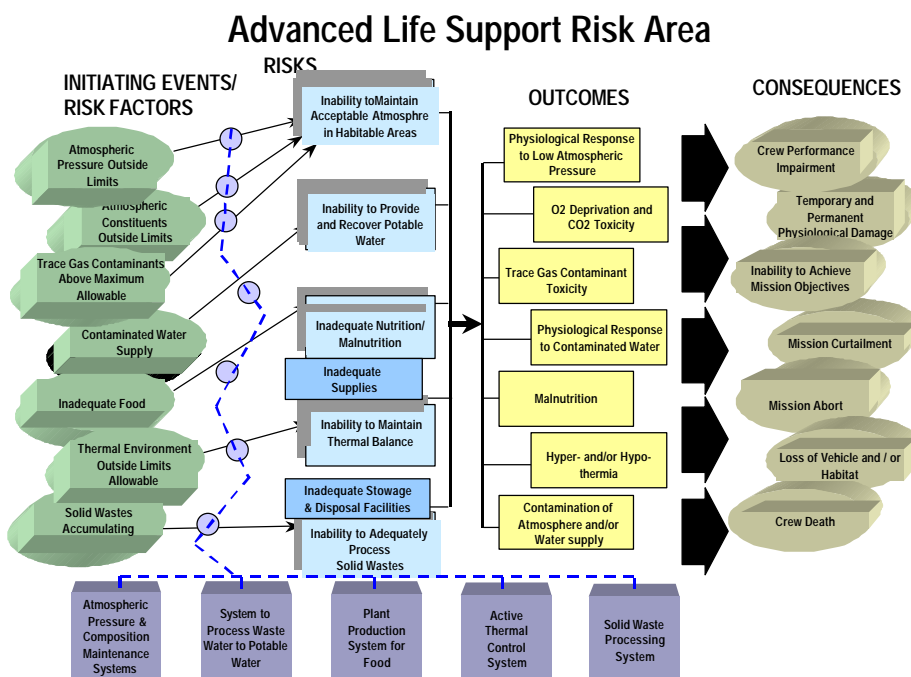
⁵ Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment./acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

*NR: Currently not rated by the discipline risk area team

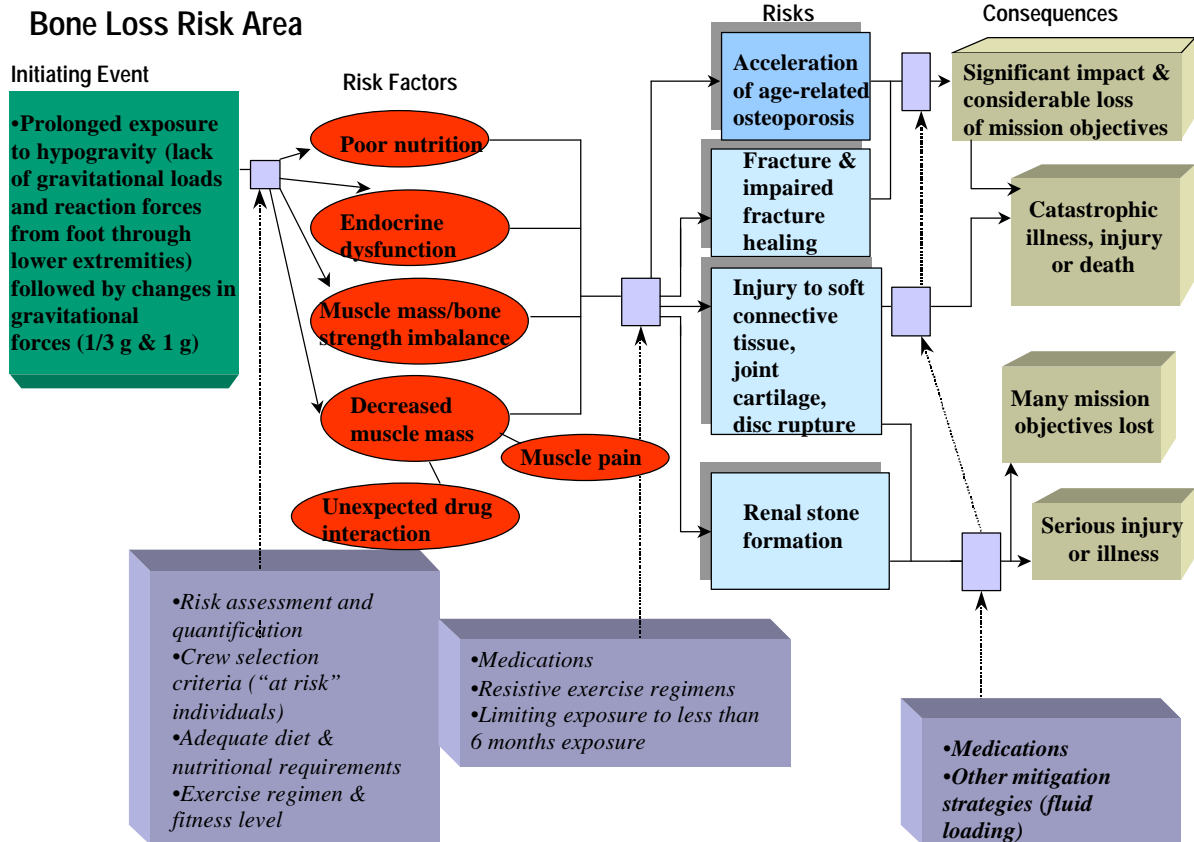
7.0 Roadmaps

Roadmaps are graphic models developed to depict a causal pathway. Each “Roadmap” shows the interrelationship among initiating events, risk factors, risks and consequences within each of the risk areas. The points at where to intervene in the process to alter the occurrence or consequences of the risk are shown as well as the different types of risk mitigations/countermeasures required to reduce and/or prevent the risk. There is no time dimension associated with the maps other than the causal sequence of events and their consequences. The timelines for individual risks are currently under development.

7.1 Advanced Life Support Roadmap

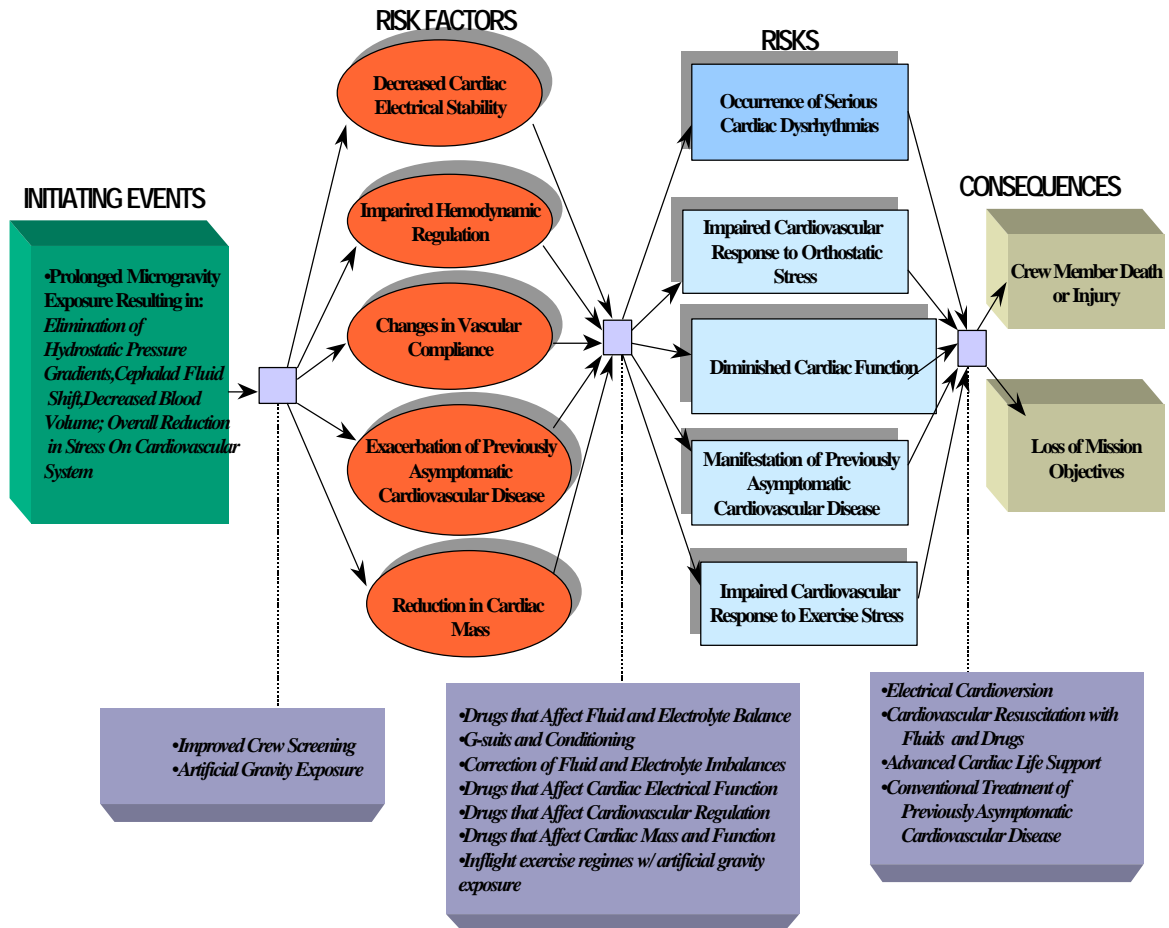


7.2 Bone Loss Roadmap

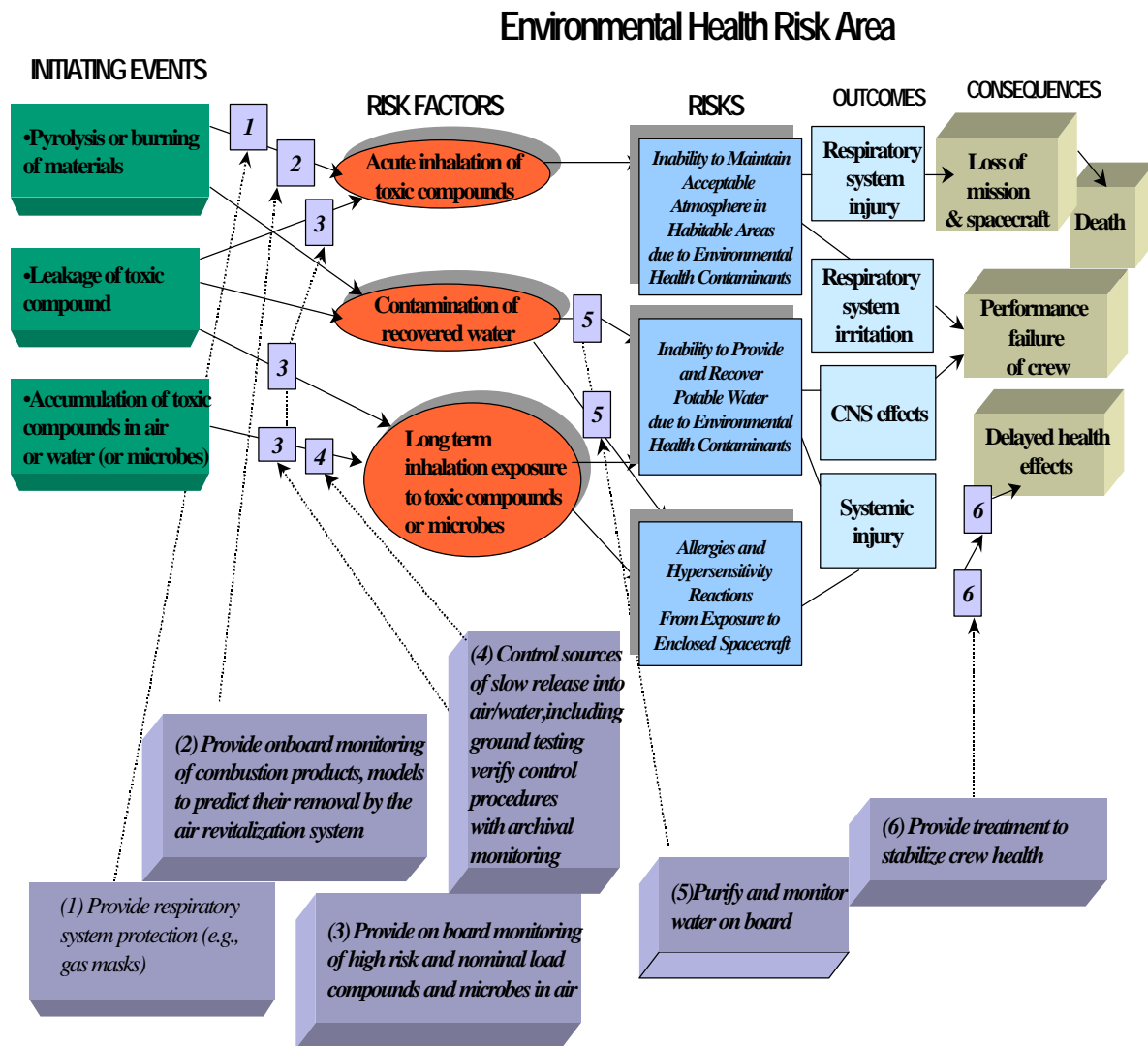


7.3 Cardiovascular Alterations Roadmap

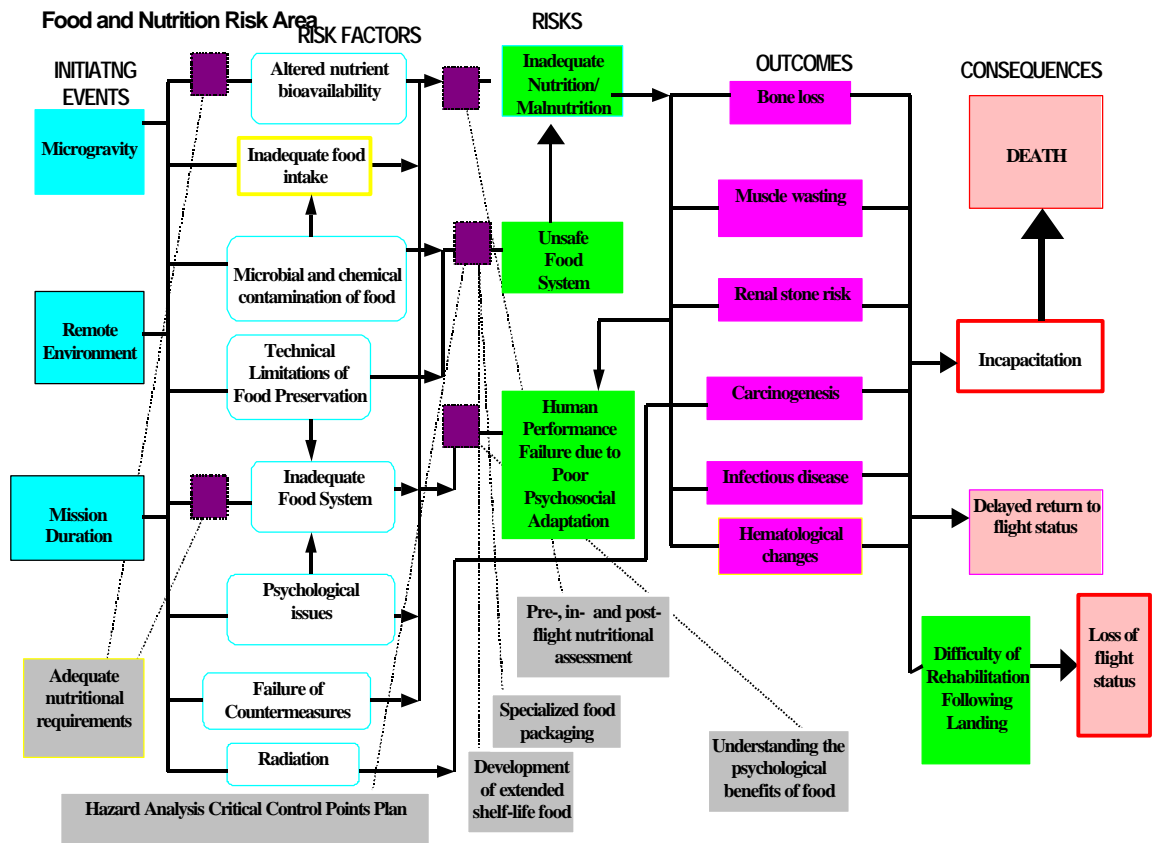
Cardiovascular Alterations Risk Area



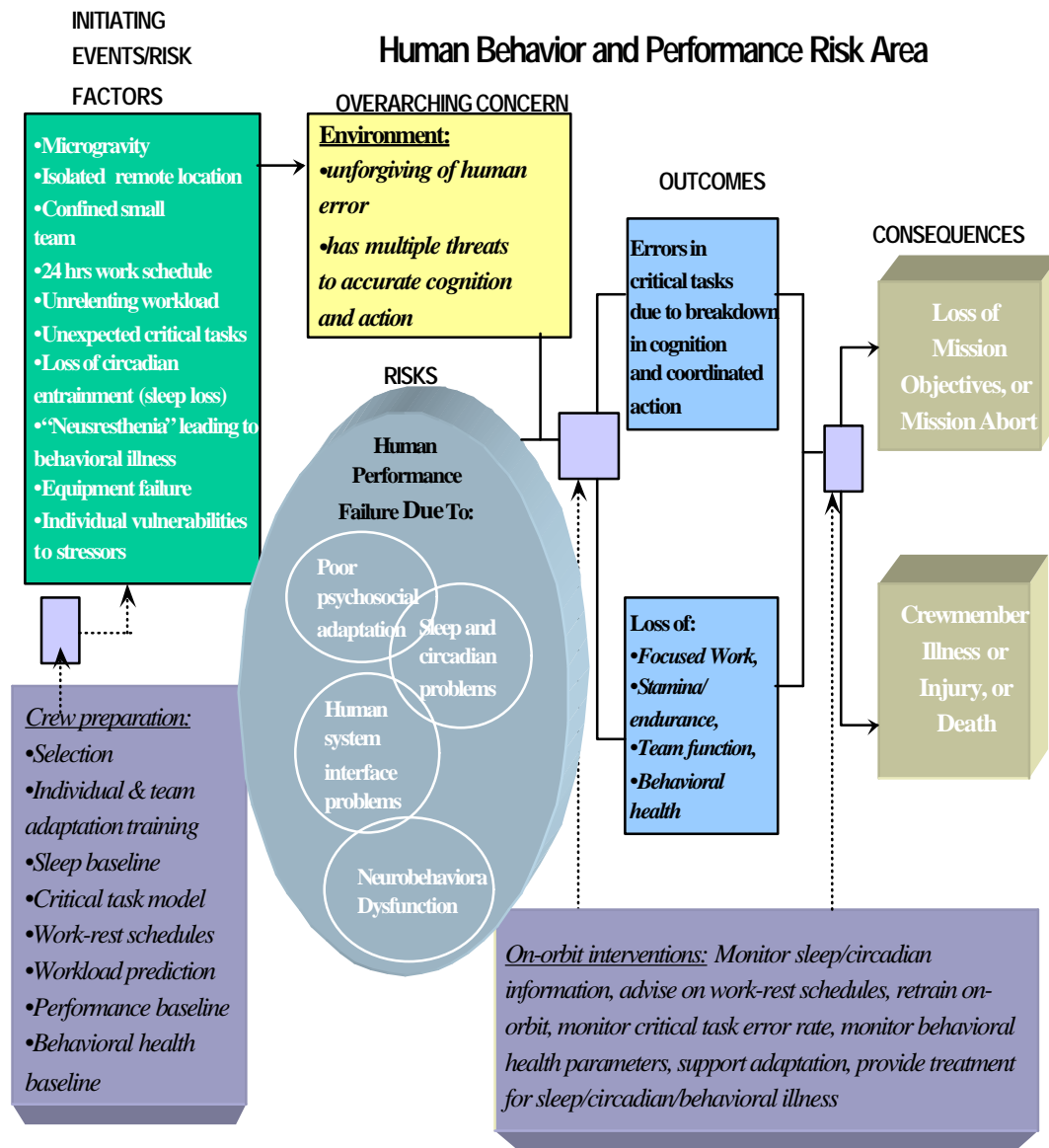
7.4 Environmental Health Roadmap



7.5 Food and Nutrition Roadmap

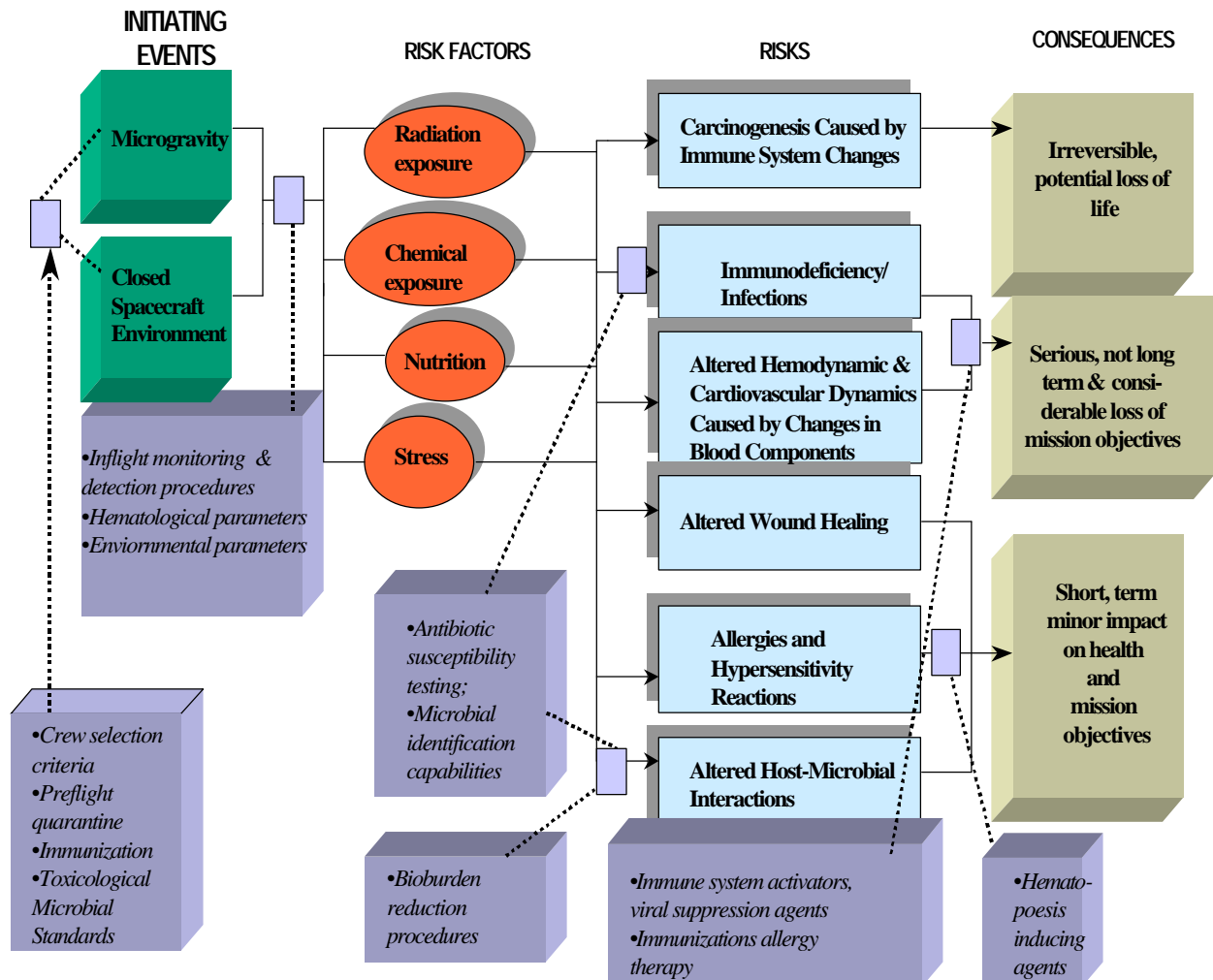


7.6 Human Behavior and Performance Roadmap



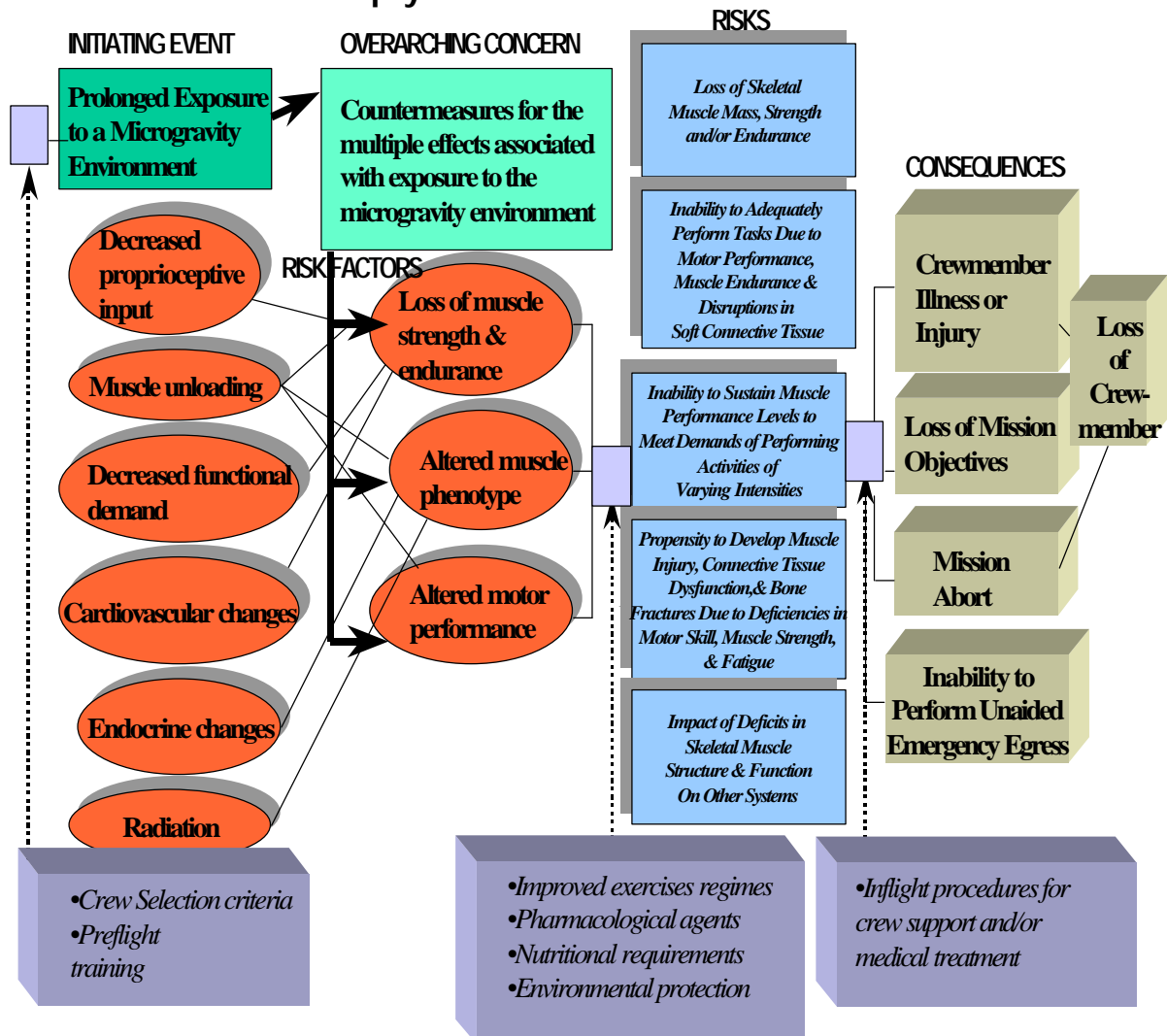
7.7 Immunology, Infection and Hematology Roadmap

Immunology, Infection and Hematology Risk Area

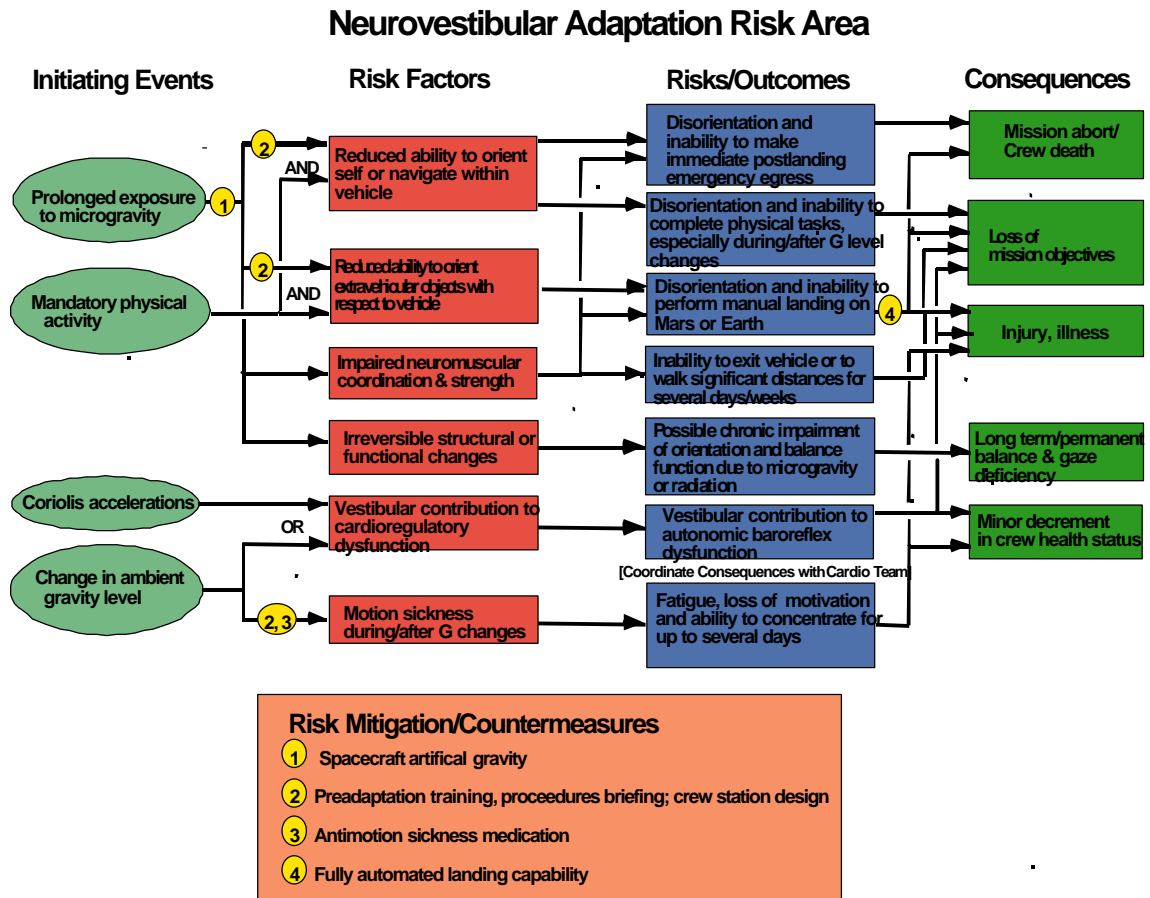


7.8 Muscle Alterations and Atrophy Roadmap

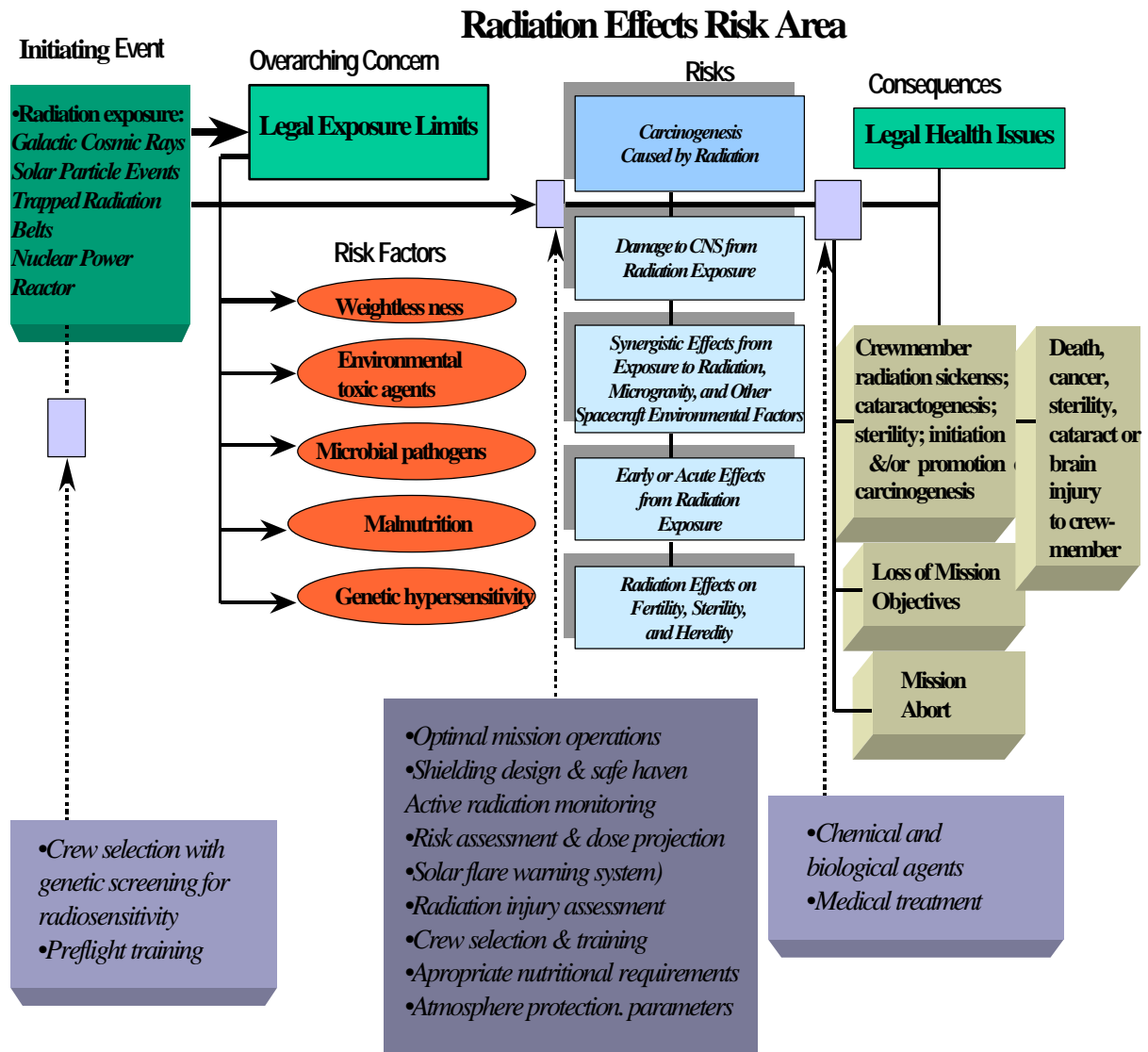
Muscle Alterations and Atrophy Risk Area



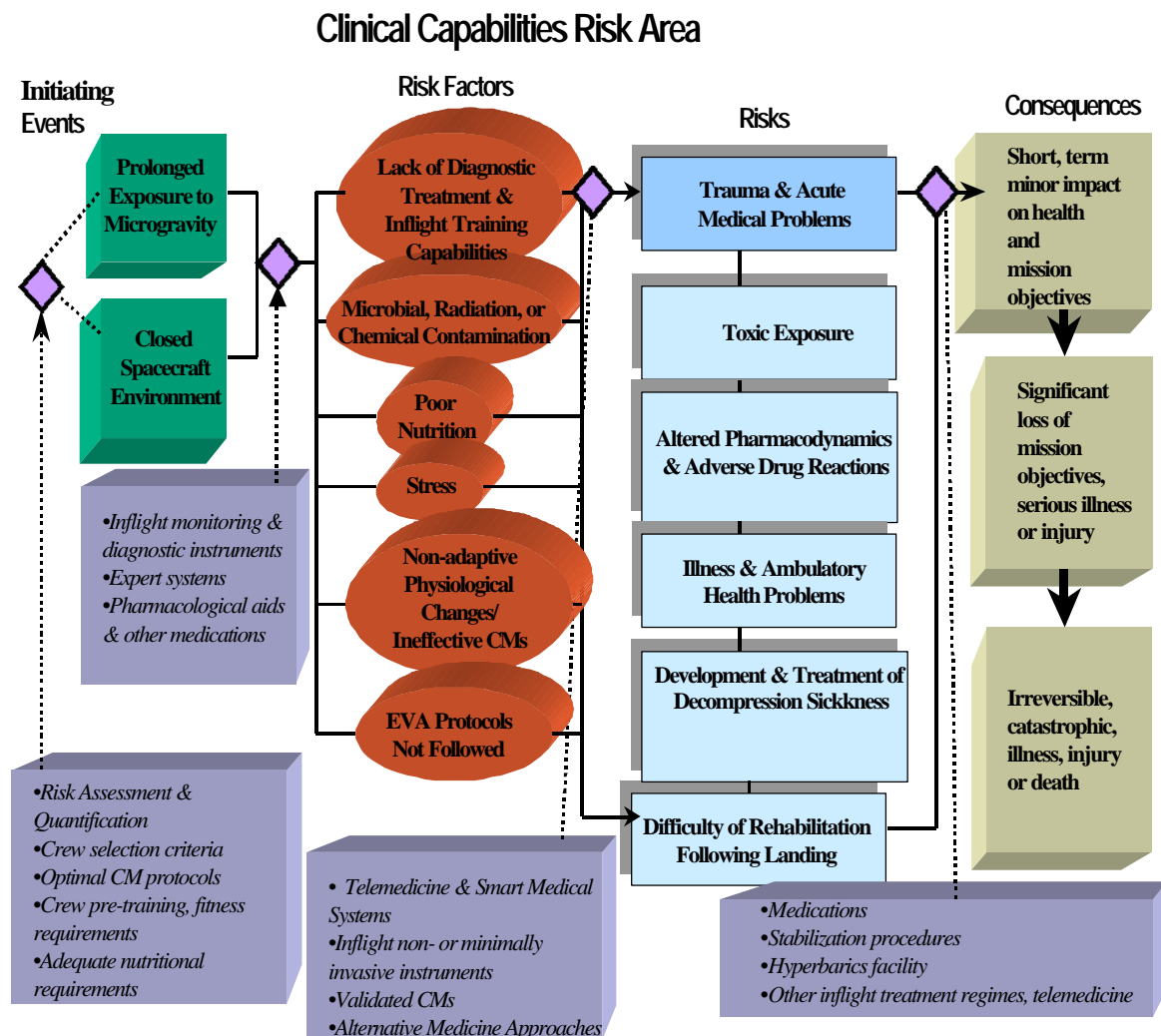
7.9 Neurovestibular Adaptation Roadmap



7.10 Radiation Effects Roadmap



7.11 Clinical Capabilities Roadmap



7.0 Appendices

Appendix -1 Risk Scoring Criteria

Appendix -2 Risk Data Sheets

Appendix -3 Table of Risks, Risk Rank and Risk
Type/Priority for All CPR Risks

A-1 – Risk Scoring Criteria

(1) Expected Occurrence of Risk

Score the expected occurrence of the risk under the two following conditions: (a) when no countermeasures or risk mitigation strategies are present; and (b) when current countermeasures or risk mitigation strategies are applied

(a) no countermeasures or risk mitigation strategies present

- 1= 0-5 %
- 2= 6-20%
- 3= 21-60%
- 4= 61-94%
- 5= ≥95-100%

(b) current countermeasures are applied

- 1= 0-5 %
- 2= 6-20%
- 3= 21-60%
- 4= 61-94%
- 5= ≥95-100%

(2) Expected Impact on Mission: If the risk were to occur what would its expected impact be on the mission in terms of mission objectives?

Score the expected mission impact of the risk on a 1 - 5 scale, where “1”=no impact or loss of mission objectives and “5”=mission abort

- 1** = no impact to mission whatsoever; no loss of mission objectives
- 2** = relatively small impact to mission; loss limited to only a few of the mission objectives
- 3** = considerable impact and considerable loss of mission objectives
- 4** = significant mission impact; many mission objectives lost, however mission is not aborted
- 5** = significant mission impact; total loss of mission objectives; mission aborted

(3) Expected Impact on Crew: If the risk were to occur what would its expected impact be on crew health and safety?

Score the expected impact to the crew according to a 1 - 5 scale, where “1”= no impact or impairment, and “5” = significant, irreversible, long term impairment, or death.

- 1** = no impact to crew
- 2** = short-term, minor injury, illness, incapacitation, or impairment to crewmember
- 3** = serious injury, illness, incapacitation or impairment but not long term
- 4** = significant and long term impairment, but not permanent
- 5** = irreversible, catastrophic impairment, or death

(4) Risk Mitigation Status:

Score the current status of the risk mitigation strategy or countermeasure to address each risk, where “1” equals mitigation status completed and understood (risk mitigated) and “5” equals no mitigation available and substantial research needed

- 1** = mitigation completed and understood
- 2** = mitigation available but not validated
- 3** = risk partially mitigated but very focused and directed research needed to lower risk
- 4** = risk partially mitigated but substantial research needed to lower risk
- 5** = no mitigation available and additional substantial research needed

A-2 Risk Data Sheets

1.0 Advanced Life Support

Risk Data Sheet

<i>Risk number</i>	1
<i>Risk area</i>	Advanced Life Support
<i>Risk title</i>	Inability to maintain acceptable atmosphere in habitable areas
<i>Contributing risk factors</i>	remoteness, crew health/susceptibility to degree of system closure
<i>Risk description</i>	Inability to control excessive atmosphere concentration CO ₂ and O ₂ , and trace contaminants in habitable areas; excessive airborne chemical pollutants, including microbial contaminants (leaks, fires, microbial degradation of biological wastes, formaldehyde, ethylene glycol, freon spills or altered virulence or antibiotic susceptibility of microorganism)
<i>Risk Rank (within risk area)</i>	1
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	Current sensors, test equipment and analysis equipment, some filtration, venting, LiOH backup compression gas storage, emergency personal breathing systems
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Electrolysis, absorption systems, oxidation, emergency personal breathing systems, real time analysis, higher fidelity sensors, "smart" control systems, insitu resources
<i>Relationship to risks within risk area and to other risk areas</i>	Environmental health
<i>Critical Questions (priority):</i>	1.01 What is the best method for controlling total atmospheric pressure, O ₂ and CO ₂ partial pressure? (2)
	1.02 What is the best CO ₂ adsorbing material and/or mechanism? (2)
	1.03 What is the best way to recover the O ₂ from the CO ₂ ? (2)
	1.04 What is the best method to control trace gas contaminants? (2)
	1.05 Are sensors available to provide environmental data? (3)
	1.06 Are sensors available to monitor performance? (3)
	1.07 What is the best monitoring and control system? (3)
<i>Important References:</i>	Spaceflight Life Support and Biospherics, Eckart, 1996
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA, 1994
	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington:DC., 1997

Risk Data Sheet

<i>Risk number</i>	2
<i>Risk area</i>	Advanced Life Support
<i>Risk title</i>	Inability to provide and recover potable water
<i>Contributing risk factors</i>	remoteness, crew health/susceptibility to degree of system closure
<i>Risk description</i>	Inability to provide and recover potable water from human-generated waste waters. Risk is failure to provide and recover water from human-generated waste waters reliably with physical properties intact (i.e., taste, odor), and with minimum power, mass, volume, and consumables; chemical and microbial contamination of spacecraft water, or altered virulence or antibiotic susceptibility of microorganisms
<i>Risk Rank (within risk area)</i>	2
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	Fuel cells, heat treatment, biocide additives, reprocessing, dumping
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Fuel cells, heat treatment, biocide additives, reprocessing, dumping; insitu resources, improved sensors and measuring devices, integrated ALS systems with plants and condensate systems
<i>Relationship to other risks within risk area and to other risk areas</i>	Environmental health
<i>Critical Questions (Priority):</i>	1.16 What is the best method for supplying potable water to use points? (3)
	1.17 What waste water collection and transport mechanisms are best? (3)
	1.18 What methods are best for removal of organic and inorganic contaminants in waste water (physiochemical, biological)? (2)
	1.19 What is the best method to add a residual biocide? (3)
	1.20 What is the best way to store and maintain potability of recycled water? (2)
	1.21 What methods (sensors) are available to measure water quality parameters? (3)
	1.22 What is the best monitoring and control system? (3)
<i>Important References:</i>	Spaceflight Life Support and Biospherics, Eckart, 1996
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA, 1994
	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington:DC, 1997

Risk Data Sheet

<i>Risk number</i>	4
<i>Risk area</i>	Advanced Life Support
<i>Risk title</i>	Inability to maintain thermal balance in habitable areas
<i>Contributing risk factors</i>	Sources of heat from other elements of the mission; orientation of the vehicle during flight; orientation of vehicle and/or habitat on planetary surface; location on planetary surface; planetary environment (temperature ranges & extremes, dust, seasonal variations, etc.); use or availability of local planetary resources
<i>Risk description</i>	Inability to acquire, transport, and reject waste heat from life support systems reliably and efficiently with minimum power, mass and volume. Capability is crucial to enabling extended human exploration of space.
<i>Risk Rank (within risk area)</i>	3
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	condensing heat exchangers
<i>Specific projected countermeasure(s) or mitigation(s)</i>	active thermal control system using membranes
<i>Relationship to other risks within risk area and to other risk areas</i>	Environmental health; human performance
<i>Critical Questions (priority):</i>	1.23 What is the best thermal working fluid for the thermal control components in habitable areas? (3)
	1.24 What materials and designs are best used to acquire waste heat (condensing heat exchangers, coldplates, etc.)? (3)
	1.25 What material and designs are best for the thermal transport components (pumps, phase separators, etc.)? (3)
	1.26 What materials and designs are best for the thermal rejection components (radiators for use on vehicles vs moon and Mars)? (2)
	1.27 What is the best way to control humidity? (3)
	1.28 Are sensors available to provide environmental data? (3)
	1.29 Are sensors available to monitor performance of the thermal system? (3)
	1.30 What is the best monitoring and control system? (3)
<i>Important References</i>	Spaceflight Life Support and Biospherics, Eckart, 1996
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA, 1994
	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington: DC, 1997

Risk Data Sheet

<i>Risk number</i>	5
<i>Risk area</i>	Advanced Life Support
<i>Risk title</i>	Inability to adequately process solid wastes
<i>Contributing risk factors</i>	Not specified
<i>Risk description</i>	Inability to adequately process solid wastes reliably with minimum power, mass, volume, and consumable. Capability is crucial to enabling extended human exploration of space & self-efficiency (i.e., independence from Earth re-supply)
<i>Risk Rank (within risk area)</i>	3
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	Storage, freeze drying
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Storage, freeze drying; incineration, bio-oxidation, methods for re-use
<i>Relationship to other risks within risk area and to other risk areas</i>	Environmental health; Human performance
<i>Critical Questions:</i>	1.31 What is the best method to process solid wastes for storage and/or disposal? (2)
	1.32 What is the best method to process solid wastes to recover resources? (2)
	1.33 What constraints should be imposed on materials such as packaging, paper, etc.? (3)
	1.34 How should solid waste streams be separated (edible plant biomass, trash and paper, feces, etc.)? (3)
	1.35 What is the best methodology for dealing with residuals? (2)
	1.36 Are sensors available to monitor performance? (3)
	1.37 What is the best monitoring and control system? (3)
<i>Important References:</i>	Spaceflight Life Support and Biospherics, Eckart, 1996
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA, 1994
	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington:DC., 1997

Risk Data Sheet

<i>Risk number</i>	53
<i>Risk area</i>	Advanced Life Support
<i>Risk title</i>	Inadequate nutrition (malnutrition) due to inability to provide and maintain a bioregenerative system
<i>Contributing risk factors</i>	Not specified
<i>Risk description</i>	Inability to provide adequate food in terms of human nutrition requirements as specified by NASA medical sciences reliably (including use of higher plants). Nutritional requirements for space include fluids, macronutrients, micronutrients, compounds or elements that may be required and compounds that may affect health status such as cholesterol, fatty acids, proportion of energy substrates, fiber, non-nutritive factors such as carotenoids, etc. Inability to provide adequate food in terms of human
<i>Risk Rank (within risk area)</i>	1
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	Stored and freeze-dried foods, stored fluids, fuel cell water, vitamin supplements
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Stored and freeze-dried foods, stored fluids, fuel cell water, vitamin supplements; edible plant production and processing, water re-cycling
<i>Relationship to other risks within risk area and to other risk areas</i>	Food and nutrition, Radiation effects
<i>Critical Questions:</i>	<p>1.09 What is the best method to grow plants with established plant production requirements including light, water, gas, gas composition and pressure, trace gas contaminants, nutrient status, mechanical support, freedom from diseases and insects? (2)</p> <p>1.10 What species and cultivars should be used to optimize production and meet nutritional requirements? (2)</p> <p>1.11 What mechanized or automated systems for planting, harvesting, and monitoring and control are required? (2)</p> <p>1.12 What methods are best to maintain genetic integrity? (2)</p> <p>1.13 What are the interfaces with the air revitalization and water recovery systems? (3)</p> <p>1.14 What processing and storage of plant products must be accommodated? (2)</p> <p>1.46 What percentage of crew food needs should be attributed to ALS plant products? (1)</p> <p>1.47 What processing processes and hardware will be required to convert ALS plant products into edible supplements to stowed food? (1)</p> <p>1.15 What are the effects of radiation on plant growth? (1)</p>
<i>Important References:</i>	<p>Spaceflight Life Support and Biospherics, Eckart, 1996</p> <p>Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA, 1994</p> <p>Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington:DC., 1977 , 1997</p>

Risk Data Sheet

<i>Risk number</i>	6
<i>Risk area</i>	Advanced Life Support
<i>Risk title</i>	Inadequate stowage and disposal facilities for solid and liquid trash generated during mission
<i>Contributing risk factors</i>	Not specified
<i>Risk description</i>	Provide a system for adequately storing, neutralizing, compacting, & potentially recycling trash generated (including clothing) throughout the mission, reliably and efficiently with minimum power, mass and volume
<i>Risk Rank (within risk area)</i>	4
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	Stowage, dumping, venting
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Recycling, innovative stowage options
<i>Relationship to other risks within risk area and to other risk areas</i>	Human performance; Environmental health
<i>Critical Questions:</i>	1.44 Could any of the solid waste be recycled in such a way as to provide building material for habitability features needed in subsequent phases of the mission? (3)
<i>Important References:</i>	

Risk Data Sheet

<i>Risk number</i>	3
<i>Risk area</i>	Advanced Life Support
<i>Risk title</i>	Inadequate supplies (including maintenance, emergency provisions, and edible food)
<i>Contributing risk factors</i>	Not specified
<i>Risk description</i>	Inadequate provisions to handle inflight maintenance requirements and the inability to provide edible food due to limited food packaging technology, reliably, efficiently, and with minimum power, mass, and volume
<i>Risk Rank (within risk area)</i>	2
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	Mission abort, re-supply
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Advanced food packaging and storage, food production, re-supply, recycling, insitu resources
<i>Relationship to other risks within risk area and to other risk areas</i>	radiation effects
<i>Critical Questions:</i>	1.45 What storm shelter supplies must be provided to allow the crew to survive radiation threats requiring retreat into save areas for prolonged time periods? (3)
<i>Important References:</i>	Not Specified

2.0 Bone Loss

Risk Data Sheet

<i>Risk number</i>	9
<i>Risk area</i>	Bone Loss
<i>Risk title</i>	Acceleration of age-related osteoporosis
<i>Contributing risk factors</i>	age, recovery rate postflight, gender, baseline BMD, diet
<i>Risk description</i>	Failure to recover bone lost during mission coupled with age-related bone loss can lead to osteoporotic fractures at a younger age. Important for long duration missions for crew health and for designing rehabilitation strategies.
<i>Risk Ranking (within risk area)</i>	1
<i>Risk Type (across risks)</i>	I
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or mitigation(s)</i>	Crew Selection; Exercise Regime
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Crew Screening and Selection for "at Risk" Individuals; Hormone Replacement Therapy; Exercise and Fitness Regimens; Rehabilitation Strategies; Spacesuit Design; Diagnostic Tools (Note: Should know enough by 2005 to avoid selecting those individuals with highest risk for acute acceleration of bone loss during a Mars mission.)
<i>Relationship to other risks within risk area and to other risk areas</i>	Muscle Alterations and Atrophy; Fracture and Impaired Fracture Healing (Bone Loss); Injury to Connective Tissue, Joint Cartilage, Disc Rupture; Clinical Capabilities
<i>Critical Questions:</i>	2.03 Will bone mass loss (e.g., 1- 1.5% per month) continue unabated for missions greater than 6 months in duration, or will it eventually plateau at some time consistent with absolute bone mineral density? Is this "minimum BMD" site-specific or consistent over numerous skeletal sites? (1)
	2.09 What are the most important predictors for bone loss during prolonged exposure to hypogravity, especially with reference to ethnicity, gender, age, baseline BMD, bone morphometry (e.g., femoral neck length)? (1)
	2.19 Is bone loss reversible and within what time frame: Can geometry and architecture return to baseline as well as BMD? (1)
	2.25 Can the pattern of reversibility be correlated with serum or urine biomarkers of bone turnover? (NR)
	2.26 How does treatment initiation in returning crew with bone loss diminish the risk of postflight fracture by facilitating more rapid return to preflight bone status? (NR)
	2.20 What is the most optimal rehabilitation regimen upon return to normal gravity to maximize return to baseline BMD and bone morphometry, especially given that muscle strength will recover more quickly than will bone strength? (2)
<i>Important References:</i>	NASA Countermeasures Final Report (1997)
<i>Current Tasks:</i>	Sub-regional Assessment of Bone Loss in the Axial Skeleton in Long Term Spaceflight (Lang, TF - 1998) Critical Question (2.03)
	Compact, High Precision, Multiple Projection DEXA Scanner (Charles, J. 1998) Critical Question (2.14)

Risk Data Sheet

<i>Risk number</i>	10
<i>Risk area</i>	Bone Loss
<i>Risk title</i>	Fracture (traumatic, stress, avulsion) and impaired fracture healing
<i>Contributing risk factors</i>	Poor nutrition, decreased muscle mass, muscle/bone strength imbalance, endocrine dysfunction can aggravate this
<i>Risk description</i>	Increased risk of fracture (traumatic, stress, avulsion) upon return to activity in 1/3 to 1 g due to hypogravity-induced bone loss.
<i>Risk Rank (within risk area)</i>	2
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or risk mitigation strategies</i>	Exercise, medications, nutrition
<i>Specific projected cm(s) or risk mitigation strategies</i>	Resistive exercise regimes, medications, preflight fitness, spacesuit design to minimize fracture risk
<i>Relationship to other risks within risk area and to other risk areas</i>	Food and nutrition, muscle alterations and atrophy
<i>Critical Questions:</i>	<p>2.01 What is the relative risk of sustaining a traumatic and/or stress fracture for a given decrement in bone mineral density or bone geometry in an astronaut-equivalent population (i.e., 30-60 year old healthy men and women) who are also physically active? (1)</p> <p>2.02 What are the mechanical loads imposed on important skeletal sites in the Martian environment of 1/3 g, given anticipated work tasks? (1)</p> <p>2.03 Will bone mass loss (e.g., 1-1.5% per month) continue unabated for missions greater than 6 months in duration, or will it eventually plateau at some time consistent with absolute bone mineral density? Is this "minimum BMD" site-specific or consistent over numerous skeletal sites? (2)</p> <p>2.04 What localized bone changes at tendon sites would contribute to increased risk of avulsion fractures (i.e., how much disparity between bone & muscle strength can be incurred without increased risk of avulsion fracture)? (2)</p> <p>2.05 Is there an additive or synergistic effect of estrogen deficiency (as in post-menopausal or amenorrheic women) and prolonged exposure to hypogravity? (4)</p> <p>2.06 What pharmacological agents will most effectively minimize the decrease in bone mass with hypogravity? Are anabolic regimes as well as anti-resorptive agents required? (1)</p> <p>2.07 What are the specifics of the optimal exercise regimen to be followed during exposure to hypogravity to minimize decreases in bone mass with regard to workout duration, intensity, frequency? Is impact loading an essential element? If so, how can it be produced in hypogravity? (1)</p> <p>2.08 Is there an optimal combination of exercise (an anabolic stimulus) and a pharmacological countermeasure (anti-resorptive) to minimize decrements in bone mass in hypogravity? (1)</p> <p>2.09 What are the most important predictors for bone loss during prolonged exposure to hypogravity, especially with reference to ethnicity, gender, age, baseline BMD, bone morphometry (e.g., femoral neck length)?</p> <p>2.10 Does hypogravity exposure change the nutritional requirements for optimal bone health (e.g., does calcium absorption decrease)? (1)</p> <p>2.11 Does prolonged exposure to hypogravity lead to impaired healing fractures? What evidence supports the alteration in vertebral morphometry during and after extended spaceflight? (4)</p> <p>2.12 What are the signal transduction pathways allowing bone cells to sense gravity and loading on bone? (2)</p> <p>2.13 Does hypogravity affect the size, viability, or differentiation of precursor bone cell populations? (2)</p> <p>2.14 What practical diagnostic tools can be utilized during multi-year missions to monitor and quantify changes in bone mass and strength (e.g., biochemical markers, DEXA, ultrasound)? (2)</p> <p>2.15 Are there important other mechanisms for bone loss with hypogravity that are critical to developing effective countermeasures (e.g., fluid shifts with altered hydrostatic pressure, changes in blood flow, immune system alterations)? (2)</p> <p>2.24 How can animal models be used to better understand the risk of fractures and impaired fracture healing? (NR)</p> <p>2.26 How does treatment initiation in returning crew with bone loss diminish the risk of postflight fracture by facilitating more rapid return to preflight bone status? (NR)</p> <p>2.23 What is the difference between relative loss of BMD and projected increase in fracture risk? Is the risk of fracture in lower extremities related to bone loss either during or after spaceflight? (NR)</p>
<i>Key References</i>	<i>Not specified</i>

Risk Data Sheet

<i>Risk number</i>	11
<i>Risk area</i>	Bone Loss
<i>Risk title</i>	Injury to soft connective tissue, joint cartilage, and intervertebral disc rupture with or without neurological complications
<i>Contributing risk factors</i>	decreased muscle strength, decreased loads on muscle and connective tissue, muscle atrophy and bone/mineral loss, biomechanical disturbances
<i>Risk description</i>	Fascia, tendon and ligament overuse or traumatic injury, joint dysfunction upon return to normal/partial gravity. Hypogravity changes to intervertebral discs may increase risk of rupture, with attendant back pain, possible neurological complications.
<i>Risk Rank (within risk area)</i>	3
<i>Risk Type (across risks)</i>	III
<i>Risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	None or not known
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Exercise protocols, suit design with protection for joints/soft tissue
<i>Relationship to other risks within risk area and to other risk areas</i>	Neurovestibular adaptations, space medicine
<i>Critical Questions:</i> <i>Important References:</i>	2.17 What is the incidence of soft connective tissue injury and pain during recovery after prolonged hypogravity or bed rest? (Use pre- and postflight analyses of MRI scan of spine and extremities and postflight follow-up studies over six months to one year.) (1)
	2.18 What countermeasures can reduce the incidence of soft connective tissue injury and pain during recovery after prolonged hypogravity or bed rest? (1)
	Not specified

Risk Data Sheet

<i>Risk number</i>	12
<i>Risk area</i>	Bone Loss
<i>Risk title</i>	Renal stone formation
<i>Contributing risk factors</i>	Inflight overloaded schedule, motion sickness on return to 1 g, decreased skeletal loads inflight, hypercalcuria risk throughout flight, decreased urine volume, increased bone resorption
<i>Risk description</i>	Urine calcium concentration is increased due to increased bone resorption during hypogravity and to decreased urine volume during periods of dehydration.
<i>Risk Rank (within risk area)</i>	4
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	2
<i>Specific current cm (s) or risk mitigations</i>	exercise, fluid loading, increased bone resorption during hypogravity and to decreased urine volume during periods of dehydration
<i>Specific projected cm(s) or risk mitigations</i>	IV fluids, dietary controls, LBNP, preflight adaptation training
<i>Relationship to other risks within risk area and to other risk areas</i>	food and nutrition, cardiovascular alterations
<i>Critical Questions:</i>	2.05 Is there an additive or synergistic effect of estrogen deficiency (as in post-menopausal or amenorrheic women) and prolonged exposure to hypogravity? (4)
	2.09 What are the most important predictors for bone loss during prolonged exposure to hypogravity, especially with reference to ethnicity, gender, age, baseline BMD, bone morphometry (e.g., femoral neck length)? (1)
	2.10 Does hypogravity exposure change the nutritional requirements for optimal bone health (e.g., does calcium absorption decrease)? (1)
	2.13 Does hypogravity affect the size, viability, or differentiation of precursor bone cell populations? (2)
	2.06 What pharmacological agents will most effectively minimize the decrease in bone mass with hypogravity? Are anabolic regimes as well as anti-resorptive agents required? (1)
	2.07 What are the specifics of the optimal exercise regimen to be followed during exposure to hypogravity to minimize decreases in bone mass with regard to workout duration, intensity, frequency? Is impact loading an essential element? If so, how can this be produced in hypogravity? (1)
	2.08 Is there an optimal combination of exercise (an anabolic stimulus) and a pharmacological countermeasure (anti-resorptive) to minimize decrements in bone mass in hypogravity? (1)
	2.21 Does existing data allow prediction of stone risk? (NR)
<i>Important References:</i>	Not specified

3.0 Cardiovascular Alterations

Risk Data Sheet

<i>Risk number</i>	13
<i>Risk area</i>	Cardiovascular Alterations
<i>Risk title</i>	Occurrence of serious cardiac dysrhythmias
<i>Contributing risk factors</i>	Fluid and Electrolyte Imbalance, Diminished Cardiac Mass
<i>Risk description</i>	Serious cardiac rhythm disturbances including ventricular tachycardia have been recorded on several occasions during spaceflight. Cardiac dysrhythmias pose a potentially lethal risk during long duration spaceflight.
<i>Risk Rank (within risk area)</i>	I
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	None
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Electrical Cardioversion, Artificial G Exposure, Anti-arrhythmic pharmaceuticals
<i>Relationship to other risks within risk area and to other risk areas</i>	Diminished Cardiac Function; Clinical Capabilities
<i>Critical Questions:</i>	3.01 Does spaceflight increase susceptibility to serious cardiac dysrhythmias and, if so, what are the mechanisms? (1)
	3.02 Can risk of serious cardiac dysrhythmias be predicted for individual crewmembers? (1)
	3.03 What countermeasures may prevent or reduce the occurrence of serious cardiac dysrhythmias during long term spaceflight? (2)
	3.04 Can serious cardiac dysrhythmias be effectively diagnosed and treated during spaceflight? (2)
<i>Important References</i>	Charles JB, Bungo MW, Fortner GW. Cardiopulmonary Function. In: Nicogossian A, Huntoon C. Pool S., and (editors). Space Physiology and Medicine. 3 rd ed. Philadelphia, PA: Lea & Febiger, 286-304, 1994.
	Hawkins WR, Zieglschmid JF. Clinical Aspects of Crew Health. In: Biomedical Results of Apollo (NASA SP-368). Johnston RS Dietlein LF, Berry CA, editors. Washington, DC: U.S. Government Printing Office, 43-81, 1975.
	Smith RF, Stanton K, Stoop D, Brown D, Januez W, King P. Vectorcardiographic Changes During Extended Spaceflight (M093): Observations at Rest and During Exercise. In: Biomedical Results of Skylab (NASA SP-377). Johnston RS and Dietlein LF, editors. Washington, DC: NASA 339-350, 1977.

Risk Data Sheet

<i>Risk number</i>	14
<i>Risk area</i>	Cardiovascular Alterations
<i>Risk title</i>	Impaired cardiovascular response to orthostatic stress
<i>Contributing risk factors</i>	plasma fluid shift, fluid intake, altered hemodynamic regulation, changes in vascular compliance
<i>Risk description</i>	Following exposure to microgravity, upright posture results in the inability to maintain adequate arterial pressure and cerebral perfusion (orthostatic or postural hypotension). This may result in syncope (loss of consciousness) during re-entry or egress. Severity increases with duration of exposure to microgravity.
<i>Risk Rank (within risk area)</i>	1
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	g suit; fluid loading
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Oral alpha agonist drugs, artificial G exposure, drugs that affect red blood cell mass, drugs and/or equipment such as peripheral tourniquets that will increase plasma volume
<i>Relationship to other risks (within risk area and to other risk areas)</i>	Clinical Capabilities, Neurovestibular Adaptation, Diminished Cardiac Function
<i>Critical Questions:</i>	3.05 What are the physiological and environmental factors by which spaceflight decreases orthostatic tolerance? (1)
	3.06 How does duration of spaceflight affect the severity and time course of orthostatic intolerance, and what are the mechanisms? (1)
	3.07 Is orthostatic intolerance likely to develop on the surface of Mars? (1)
	3.08 Can spaceflight-induced orthostatic intolerance be predicted for individual crewmembers? (1)
	3.09 What countermeasures can be developed to overcome or prevent orthostatic intolerance? (1)
<i>Important References</i>	(1) Task Force Final Report on Countermeasures, NASA, Space Life Sciences, May 1997
	(2) Space Medicine Monitoring and Countermeasures Project Report, NASA, Johnson Space Center, October, 1997
	(3) Charles JB, Bungo MW, Fortner GW. Cardiopulmonary Function. In: Nicogossian A, Huntoon C. Pool S., editors. Space Physiology and Medicine. 3 rd ed. Philadelphia, PA: Lea & Febiger, 286-304, 1994.

Risk Data Sheet

<i>Risk number</i>	15
<i>Risk area</i>	Cardiovascular Alterations
<i>Risk title</i>	Diminished cardiac function
<i>Contributing risk factors</i>	Reduction of stress on heart over prolonged period in weightlessness
<i>Risk description</i>	Short duration spaceflight has been associated with a decrease in cardiac mass. Long duration spaceflight may result in greater decrease in cardiac mass and additional alterations which may diminish cardiac function and could be irreversible.
<i>Risk Rank (within risk area)</i>	2
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	None
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Drugs that affect cardiac mass and function, artificial G exposure with exercise (bicycle centrifuge).
<i>Relationship to other risks within risk area or other risk areas</i>	Clinical Capabilities, Impaired Cardiovascular Response to Exercise Stress
<i>Critical Questions:</i>	3.17 Does long duration spaceflight lead to diminished cardiac function and, if so, what are the mechanisms and is the process reversible? (2)
	3.18 What is the extent of reduction in cardiac mass associated with long duration spaceflight and what are the mechanisms? (2)
	3.19 Can susceptibility to reduced cardiac function be predicted for individual crewmembers? (2)
	3.20 What countermeasures may be effective in mitigating the risk? (2)
<i>Important References:</i>	Blomqvist CG, Lane LD, Wright SJ, et al. Cardiovascular regulation at microgravity. In: <i>Scientific Results of the German Spacelab Mission D-2, Proceedings of Symposium at Norderney</i> , Sahm PR, Keller MH, and Schiewe B, editors. Wissenschaftliche Projektführung D2, RWTH Aachen, Care of DLR, Köln, pp. 688-690.

Risk Data Sheet

<i>Risk number</i>	16
<i>Risk area</i>	Cardiovascular Alterations
<i>Risk title</i>	Manifestation of previously asymptomatic cardiovascular disease
<i>Contributing risk factors</i>	Lack of sufficiently sensitive screening measures
<i>Risk description</i>	There have been cardiac events during spaceflight that have impacted mission objectives. Spaceflight may aggravate underlying cardiovascular disease, such as coronary artery disease. Such problem may become more prevalent as crewmembers are drawn from populations at higher risk for cardiovascular disease (e.g., on the basis of age, gender, and diversity).
<i>Risk Rank (within risk area)</i>	3
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	Screening with treadmill test and 2D surface echocardiogram
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Incorporation of more sensitive and specific screening methods based on demographic profile.
<i>Relationship to other risks within risk area and to other risk areas</i>	Clinical Capabilities
<i>Critical Questions:</i>	3.14 Are cardiovascular diseases are likely to be aggravated by spaceflight and, if so, which ones and by what mechanisms? (1)
	3.15 What improved screening methods might identify crewmembers with underlying cardiovascular disease which may be aggravated by spaceflight? (1)
	3.16 What countermeasures may be effective in mitigating the risk? (2)
<i>Important References:</i>	Not specified

Risk Data Sheet

<i>Risk number</i>	17
<i>Risk area</i>	Cardiovascular Alterations
<i>Risk title</i>	Impaired cardiovascular response to exercise stress
<i>Contributing risk factors</i>	Diminished Cardiac Function, decreased blood volume
<i>Risk description</i>	Spaceflight results in decreased aerobic exercise capacity upon re-entry into a gravitational field, resulting in impaired ability to perform strenuous tasks.
<i>Risk Rank (within risk area)</i>	4
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or mitigation(s)</i>	Exercise in flight
<i>Specific projected countermeasures or risk mitigations</i>	Exercise in flight coupled with artificial G exposure (bicycle centrifuge), Drugs that affect cardiac mass and function.
<i>Relationship to other risks within risk area and to other risk areas</i>	Muscle Alterations and Atrophy, Clinical Capabilities, Diminished Cardiac Function
<i>Critical Questions:</i>	3.10 What are the physiological and environmental factors by which spaceflight decreases aerobic exercise capacity? (1)
	3.11 How does duration of spaceflight affect the severity of limitation of exercise capacity? (1)
	3.12 Can aerobic exercise capacity limitation be predicted for individual crewmembers? (2)
	3.13 What countermeasures can be developed to overcome aerobic exercise capacity limitation? (2)
<i>Important References</i>	Shykoff BE, Farhi LE, Olszowka AJ, et al. Cardiovascular response to submaximal exercise in sustained microgravity. J. Appl. Physiol., 81:26-32, 1996.
	Michel EL, Rummel JA, Sawin CF, Buderer MC, Lem JD. Results of Skylab Medical Experiment M171: metabolic activity. In: <i>Biomedical Results from Skylab</i> , Johnston RS and Dietlein LF, editors. Washington, DC: National Aeronautics and Space Administration, 1977, pp. 372-387.
	Rummel JA, Sawin CF, Michel EL. Exercise response. In: <i>Biomedical Results of Apollo</i> , Johnston RS, Dietlein LF, and Berry CF, editors. Washington DC: National Aeronautics and Space Administration, 1975, pp. 265-275.

4.0 Environmental Health

Risk Data Sheet

<i>Risk number</i>	51
<i>Risk area</i>	Environmental Health
<i>Risk title</i>	Inability to maintain acceptable atmosphere in habitable areas due to environmental health contaminants
<i>Contributing Risk factors</i>	remoteness, crew health/susceptibility to degree of system closure
<i>Risk description</i>	Inability to control excessive atmosphere CO ₂ and O ₂ concentration, and trace contaminants in habitable areas; excessive airborne chemical pollutants, including microbial contaminants (including leaks, fires microbial degradation of biological wastes, formaldehyde, ethylene glycol, freon spills); or altered virulence or antibiotic susceptibility of microorganisms
<i>Risk Rank (within risk area)</i>	1
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	Not specified
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Not specified
<i>Relationship to other risks within risk area and to other risk areas</i>	Advanced Life Support; Immunology, Infection and Hematology
<i>Critical Questions:</i>	<p>4.01 What are the most likely sources of severe air or water pollution and how can these sources be controlled over long periods of time? (1)</p> <p>4.02 What are the acceptable numbers and kinds of microorganisms in air, water, food, and surfaces? (1)</p> <p>4.03 What resources are required to manage plausible environmental risks during long and remote missions? (1)</p> <p>4.04 How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures? (2)</p> <p>4.05 What approaches to setting exposure standards may be used when insufficient data are available to allow prediction of acceptable exposure levels? (1)</p> <p>4.06 How much risk do materials that condense inside the spacecraft pose to the environmental health? (2)</p> <p>4.07 What impact do spaceflight-induced biological, physiological, & immunological changes have on the susceptibility of crewmembers to toxic substances in the air and water? (2)</p> <p>4.08 What are the effects of exposure to ultrafine and larger (respirable and non-respirable) particles (e.g. Martian dust) on crew health, safety, and performance? (2)</p> <p>4.11 What are the interactions of microbes, chemicals and plants in a CELSS on air and water quality? (2)</p> <p>4.12 What are the effects of the space environment on microbial interactions with space systems and humans? (2)</p> <p>4.13 How rapidly can acceptable air quality be recovered after a severe pollution condition and what is the effect on humidity condensate and the water recovery system? (2)</p> <p>4.15 How can automated real-time systems be used to monitor air and water quality for a Mars mission, and how will the crew interpret the results without ground support? (1)</p>
<i>Important References:</i>	<p>Pool, S.L. Ethylene Glycol Treatise. NASA/JSC Memorandum SD2-97-542, September 15, 1997</p> <p>Nicogossian, A.E. et al., Crew Health in The Apollo-Soyuz Test Project Medical Report, NASA SP-411, 1977</p> <p>Huntoon, C.L., Toxicological Analysis of STS-40 Atmosphere, NASA/JSC Memorandum, SD4/01,93-251, July 6, 1991; Toxicological Analysis of STS-55 Atmosphere, NASA/JSC Memorandum SD4-93-251, July 6, 1993</p> <p>James, J.T., Toxicological Assessment of Air Samples Taken after the Oxygen-Generator Fire on Mir, NASA/JSC Memorandum SD2-97-513, April 10,1997</p> <p>James, J.T., Toxicological Assessment of Air Contaminants during the Mir 19 Expedition, 19??</p>

Risk Data Sheet

<i>Risk number</i>	52
<i>Risk area</i>	Environmental Health
<i>Risk title</i>	Inability to provide and recover potable water due to environmental health contaminants
<i>Contributing Risk factors</i>	remoteness, crew health/susceptibility to degree of system closure
<i>Risk description</i>	Inability to provide and recover potable water from human-generated waste waters. Risk is failure to provide and recover water from human-generated waste waters reliably with physical properties intact (i.e., taste, odor), and with minimum power, mass, volume, and consumables; Chemical and microbial contamination of spacecraft water, and altered virulence or antibiotic susceptibility of microorganisms
<i>Risk Rank (within risk area)</i>	2
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	Not specified
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Not specified
<i>Relationship to other risks within risk area and to other risk areas</i>	Advanced Life Support; Immunology, Infection and Hematology
<i>Critical Questions:</i>	4.01 What are the most likely sources of severe air or water pollution and how can these sources be controlled over long periods of time? (1)
	4.02 What are the acceptable numbers and kinds of microorganisms in air, water, food, and surfaces? (1)
	4.03 What resources are required to manage plausible environmental risks during long and remote missions? (1)
	4.04 How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures? (2)
	4.05 What approaches to setting exposure standards may be used when insufficient data are available to allow prediction of acceptable exposure levels? (2)
	4.07 What impact do spaceflight-induced biological, physiological, & immunological changes have on the susceptibility of crewmembers to toxic substances in the air and water? (2)
	4.11 What are the interactions of microbes, chemicals and plants in a CELSS on air and water quality? (2)
	4.12 What are the effects of the space environment on microbial interactions with space systems and humans? (2)
	4.13 How rapidly can acceptable air quality be recovered after a severe pollution condition and what is the effect on humidity condensate and the water recovery system? (2)
	4.15 How can automated real-time systems be used to monitor air and water quality for a Mars mission, and how will the crew interpret the results without ground support? (1)
<i>Important References:</i>	Carter, D.L., Phase III Integrated Water Recovery Testing as MSFC: ISS Recipient Mode Test Results and Lessons Learned. ICES Paper, No. 972375, July 1997
	Pierre et al., Collection and Chemical Analysis of Potable Water and Humidity Condensate from the Mir Space Station. ICES Paper No., 972462, July 1997

Risk Data Sheet

<i>Risk number</i>	50
<i>Risk area</i>	Environmental Health
<i>Risk title</i>	Allergies and Hypersensitivity Reactions from Exposure to the Enclosed Spacecraft and Other Environmental Factors
<i>Contributing Risk factors</i>	chemically sensitive individuals or altered immune responses, impaired pulmonary capacity
<i>Risk description</i>	Allergic hypersensitivity caused by exposure to environmental agents (chemical and microbial)
<i>Risk Rank (within risk area)</i>	3
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or mitigation(s)</i>	Limited medical screening for sensitivities
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Expanded medical screening for hypersensitivities
<i>Relationship to other risks within risk area and to other risk areas</i>	Immunology, infection and hematology
<i>Critical Questions:</i>	4.07 What impact do spaceflight-induced biological, physiological, & immunological changes have on the susceptibility of crewmembers to toxic substances in the air and water? (2)
	4.08 What are the effects of exposure to ultrafine and larger (respirable and non-respirable) particles (e.g., Martian dust) on crew health, safety and performance? (2)
	4.14 How will persons who are hypersensitive to chemicals and microbes in air and water be identified? (2)
	4.16 If hypersensitivity develops during spaceflight, how will individuals be treated? (1)
<i>Important References:</i>	Not specified

5.0 Food and Nutrition

Risk Data Sheet

<i>Risk number</i>	7
<i>Risk area</i>	Food and Nutrition
<i>Risk title</i>	Inadequate Nutrition (Malnutrition)
<i>Contributing risk factors</i>	Inadequate nutritional requirements, inability to provide food, improper food intake, stress, countermeasures induced-alterations in nutrient requirements
<i>Risk description</i>	Inability to provide adequate food in terms of human nutrition requirements as specified by NASA medical sciences reliably (including use of higher plants). Nutritional requirements for space include fluids, macronutrients, micronutrients, compounds or elements that may be required and compounds that may affect health status such as cholesterol, fatty acids, proportion of energy substrates, fiber, non-nutritive factors such as carotenoids, etc. Requirements must take into account any of the changes in the sensorisystem that might influence taste and smell and the role of countermeasures induced-alterations on nutrient requirements. All U.S. space crews to date have experienced nutritional deficiencies.
<i>Risk Rank (within risk area)</i>	1
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	Nutrition requirements based upon extrapolation , infrequent nutrient intake monitoring
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Complete inflight nutrient assessment, enhanced food system, improved countermeasures, assessment of food psychosocial importance
<i>Relationship to other risks within risk area and other risk areas</i>	unsafe food system, loss of muscle strength, bone fractures, psychogenic or chronogenic illness
<i>Critical Questions (priority):</i>	5.03 What are the nutritional requirements for exploration missions, e.g. calories, protein, calcium, iron, antioxidants, iodine, vitamin D, electrolytes? (1)
	5.05 What are the psychosocial requirements of the food system? (2)
	5.08 What technology will be required to develop a viable food system? (2)
	5.09 What type(s) of food system(s) should be used? (1)
	5.07 What monitoring method should be used to assure food safety during the entire mission? (2)
	5.06 What are the sensory changes (taste, odor, etc.) that occur during spaceflight? (4)
	5.04 What are the potential impacts of countermeasures on nutritional requirements? (1)
	5.02 What are the impacts of changing gravity on the food system i.e., galley? (3)
	5.10 What are the means of monitoring nutritional status during the mission? (3)
	5.01 How much flight access is required to answer above questions? (2)
<i>Important References</i>	Modern Nutrition In Health and Disease, 9 th edition
	NASA Johnson Space Center. Nutritional Requirements for International Space Station Missions Up To 360 Days. JSC-28038; 1996.

Risk Data Sheet

<i>Risk number</i>	8
<i>Risk Area</i>	Food and Nutrition
<i>Risk title</i>	Unsafe food systems
<i>Contributing risk factors</i>	chemical or microbial contamination, packaging, environmental control
<i>Risk description</i>	Inability to provide viable food system that: meets nutritional requirements, is safe in terms of spoilage or contamination, and is consistent with crew compliance issues (e.g., changes in taste, odor, preparation, or eating preferences)
<i>Risk Rank (within risk area)</i>	2
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	Food packaging, Hazard Analysis Critical Control Point processing, testing and evaluation
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Development of extended shelf life food, special packaging for exploration missions, nutrient loss studies
<i>Relationship to other risks and other risk areas</i>	malnutrition
<i>Critical Questions (priority):</i>	5.13 What are the effects of extended space travel on the sensory and nutrient properties of food? (2)
	5.08 What technology will be required to develop a viable food system? (1)
	5.09 What type(s) of food system(s) should be used? (1)
	5.07 What monitoring method should be used to assure food safety during the entire mission? (2)
	5.02 What are the impacts of changing gravity on the food system i.e., galley? (3)
	5.11 What type of packaging is required? (1)
	5.12 What is the risk of chemical and microbial contamination? (1)
<i>Important References</i>	5.01 How much flight access is required to answer above questions? (4)
	Johnston, R. S. and Dietlein, L. F. Biomedical results from Skylab. Washington DC: NASA; 1977.
	Lane, H.W., Smith, S. M., Rice, B. L. and Bourland, C. T. Nutrition in space: lessons from the past applied to the future. A J Clin Nutr 60:801S-805S; 1994.
	NASA Johnson Space Center. Nutritional Requirements for International Space Station Missions Up To 360 Days. JSC-28038; 1996.
	Smith, M.C., Heidelbaugh, N.D., Rambaut, P.C., Rapp, R.M., Wheeler, H.O., Huber, C. S., and Bourland, C. T. Biomedical Results of Apollo. U.S. Government Printing Office; 1975. Modern Nutrition In Health and Disease, 9 th edition

Risk Data Sheet

<i>Risk number</i>	55
<i>Risk area</i>	Food and Nutrition
<i>Risk title</i>	Human performance failure due to nutritional deficiencies
<i>Contributing risk factors</i>	Malnutrition, inadequate nutrition requirements, stress, boredom
<i>Risk description</i>	The combination of limited food sources, physiological changes, potential stress, and other factors may have long term consequences on crew performance. Both physical and cognitive performance is related to adequate nutrition.
<i>Risk Rank (within risk area)</i>	3
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or mitigation(s)</i>	Palatable and acceptable food, proper knowledge of nutrition requirements
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Refined nutritional requirements, understanding and implementation of an acceptable food system, understanding the psychological benefits of food
<i>Relationship to other risks</i>	malnutrition, unsafe food system
<i>Critical Questions</i>	5.05 What are the psychosocial requirements of the food system? (2)
	5.03 What are the nutritional requirements for exploration missions (e.g., calories, protein, calcium, iron, antioxidants, iodine, vitamin D, electrolytes)? (1)
	5.14 What is an acceptable food system? (2)
	5.01 How much flight access is required to answer above questions? (3)
<i>Important References</i>	NASA Johnson Space Center. Nutritional Requirements for International Space Station Missions Up To 360 Days. JSC-28038; 1996.
	Lane, H.W., Smith, S. M., Rice, B. L. and Bourland, C. T. Nutrition in space: lessons from the past applied to the future. A J Clin Nutr 60:801S-805S; 1994.
	Modern Nutrition In Health and Disease, 9 th edition

Risk Data Sheet

<i>Risk number</i>	54
<i>Risk area</i>	Food and Nutrition
<i>Risk title</i>	Difficulty of rehabilitation following landing due to nutritional deficiencies
<i>Contributing risk factors</i>	Bone loss, renal disease, infectious disease, radiation biochemical changes, muscle wasting, decreased red blood cell mass
<i>Risk description</i>	Excessive time required to return to health and full duty status
<i>Risk Rank (within risk area)</i>	4
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or mitigation(s)</i>	NONE
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Preflight nutritional assessment to prevent any decrements of nutritional status prior to mission, a space flight food system that supports the maintenance of nutrition status, post flight nutritional assessment and dietary counseling by a registered dietitian. Research to determine if there are nutritional issues specifically related to spaceflight.
<i>Relationship to other risks within risk area and to other risk areas</i>	malnutrition, muscle skeletal systems, aerobic exercise.
<i>Critical Questions</i>	5.03 What are the nutritional requirements for exploration missions, e.g. calories, protein, calcium, iron, antioxidants, iodine, vitamin D, electrolytes? (1)
	5.15 What are the decrements in nutritional status due to long term spaceflight? (1)
	5.16 What monitoring (biochemical, anthropometric, clinical assessments) during rehabilitation is required? (3)
	5.17 What level of dietary counseling is needed for crewmembers during rehabilitation? (3)
	5.18 Are there inflight countermeasures that affect nutritional status (promote or cause decrements)? (2)
<i>Important References</i>	Modern Nutrition In Health and Disease, 9 th edition

6.0 Human Behavior and Performance

Risk Data Sheet

<i>Risk number</i>	18
<i>Risk area</i>	
<i>Risk title</i>	Human Performance Failure Because of Poor Psychosocial Adaptation
<i>Contributing risk factors</i>	Psychosocial Adaptation
<i>Risk description</i>	
<i>Risk Rank (within discipline)</i>	1
<i>Risk Type (across risks)</i>	I
<i>Current risk mitigation status</i>	4
<i>Specific current cm(s) or mitigation(s)</i>	1. Limited Preflight Training; 2. Inflight Psychological Support
<i>Specific projected cm(s) or mitigation(s)</i>	1. Monitoring & Early Detection of Adaptation problems; 2. Predictive model of adaptability to long duration missions; 3. Enhanced Preflight Training; 4. Individual and team selection for long duration missions
<i>Relationship to other risks and to other risk areas</i>	see other Human behavior and performance risks
<i>Critical Questions (priority):</i>	<p>6.01 What are the fundamental behavioral and social stressors during long duration missions that will most likely affect crew performance, both individual and team? (1)</p> <p>6.02 What model(s) of psychological adaptation in isolated and confined environments will best predict the effect on individual and team performance over the course of the mission, and what tools can best monitor these models? (2)</p> <p>6.03 What behaviors, experiences, personality traits, and leadership styles in crewmembers most contribute to optimal performance? How are these factors related to team performance? (2)</p> <p>6.04 What crewmember behaviors, experiences, personality traits, and leadership styles that optimize performance can be identified during the selection process and be used to select and assemble the best teams for long duration missions? (2)</p> <p>6.17 What are the systems of knowledge, psychosocial support methods, attitudes, and behavior towards mission operations used by agency management, ground controllers, crewmembers and their families? How do these systems influence individual and group performance and behavior? (2)</p>
<i>Important References</i>	<p>Manzey, D., Albrecht, S., and Fassenbender, C. Psychological countermeasures for extended manned spaceflights. <i>Acta Astronautica</i>, Vol. 35, No. 4/5, pp.339-361, 1979</p> <p>Connors, M.M., Harrison, A.A. and Faren, R.A. <i>Living Aloft: Human requirements for extended spaceflight</i>. NASA SP-483, Washington, D.C., National Aeronautics and Space Administration, 1985</p> <p>Stuster, J. <i>Bold endeavors: Lessons from polar and space exploration</i>. Annapolis, MD. Naval Institute Press, 1996</p> <p>Lugg, D. Physiological adaptation and health of an expedition in Antarctica with comment on behavioral adaptation. Australian National Antarctic Research Expedition (ANARE) Scientific Report, Series B (4), No. 126. Canberra, Australia: ANARE, 1977</p> <p>Harrison, A.A., Clearwater, Y.A., and McKay C.A. (eds), <i>From Antarctica to outer space: Life in Isolation and Confinement</i>. New York: Springer-Verlag, 1991</p> <p>Miller, J. and Koblick, J. <i>Living and working in the sea</i>. New York: Van Nostrand Reinhold Company, Inc., 1984</p>

Risk Data Sheet

<i>Risk number</i>	19
<i>Risk area</i>	Human Behavior and Performance
<i>Risk title</i>	Human Performance Failure Because of Sleep and Circadian Rhythm Problems
<i>Contributing risk factors</i>	Sleep and Circadian Rhythms
<i>Risk description</i>	Human performance failure due to disruption of circadian phase, amplitude, period, or entrainment, and/or human performance failure due to acute or chronic degradation of sleep quality or quantity
<i>Risk Rank (within discipline risks)</i>	2
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	4
<i>Specific current cm(s) or mitigation(s)</i>	1. Pre-flight and in-flight sleep shifting; 2. Medications; and 3. Scheduling constraints in Appendix K
<i>Specific projected cm(s) or mitigation(s)</i>	1. Model of performance deficit based on sleep and circadian data; 2. Sleep/circadian rhythm re-adjust tools (e.g., light treatment); 3. Individual active noise cancellation; 4. Ability to monitor sleep and circadian parameters unobtrusively
<i>Relationship, to other risks and other risk areas</i>	See other Human Behavior and Performance risks
<i>Critical Questions (Priority):</i>	<p>6.05 What are the acute and long term effects of exposure to the space environment on biological rhythmicity on sleep architecture, quantity and quality, and their relationship to performance capability? (1)</p> <p>6.06 Which countermeasures or combination of behavioral and physiological countermeasures will optimally mitigate specific performance problems associated with sleep loss and circadian disturbances during a Mars mission?(1)</p> <p>6.07 What are the long term effects of countermeasures employed to mitigate performance problems with sleep loss and circadian disturbances during a Mars mission? (2)</p> <p>6.08 What are the best methods for inflight monitoring of the status of sleep and circadian functioning and for assessing the effects of sleep loss and circadian dysrhythmia on performance capability that are also portable and non-intrusive in the spaceflight environment? (2)</p> <p>6.10 What workload schedule(s) per workday will best enhance crew performance and mitigate adverse effects of the space environment? (2)</p> <p>6.21 What mathematical and experimental models best predict performance problems associated with sleep-wake and work history and circadian rhythm status, and also provide guidelines for successful countermeasure strategies? (2)</p> <p>6.18 What individual biological and behavioral characteristics will best predict successful adaptation to long term spaceflight of sleep and circadian physiology and the neurobehavioral performance functions they regulate? (NR)</p>
<i>Important References</i>	<p>Alyakrinski, BS., Current status of space biorhythmology. Translation: Space Biology and Aerospace Medicine. USSR, 2:1-13, 1977</p> <p>Saiki, H. and Nakaya, M. Dynamics of sleep patterns during prolonged simulated weightlessness. In: Holmquist, R. and Stickland, A., (Eds.), COSPAR Life Sciences and Space Research, Vol. XV. Oxford: Pergamon Press, pp. 224-231, 1971</p> <p>Santy, P., Kapanka, H., Davis, J., and Stewart, D. Analysis of sleep on Shuttle missions. Aviation Space Environmental Medicine, 59:1094-1097, 1988</p> <p>Kuklinski, P. and Wegmann, H.M. Biomedical investigations on payload specialist during spacelab simulation ASSESSII, Preprints Annual Scientific Meeting, Aerospace Medical Association, Washington, DC, May 14-17, pp. 338-339, 1979</p> <p>Stampi, C. Sleep and circadian rhythms in space. Journal of Clinical Psychology, 34: 518-534, 1994</p>

Risk Data Sheet

<i>Risk number</i>	20
<i>Risk area</i>	Human Behavior and Performance
<i>Risk title</i>	Human Performance Failure Because of Human System Interface Problems and Ineffective Habitat, Equipment Design, Workload, or Inflight Information and Training Systems
<i>Contributing risk factors</i>	Human-Systems Interface, Habitability, Information Management and Training
<i>Risk description</i>	
<i>Risk Rank (within discipline risks)</i>	3
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	3
<i>Specific current cm(s) or mitigation(s)</i>	1. Selection of crew; 2. Scheduling; 3. Training for tasks; 4. Detection by self report; 5. HFE design guidelines for h/w & s/w
<i>Specific projected cm(s) or mitigation(s)</i>	1. In-flight critical task capabilities assessment; 2. Predictive models of workload and performance failure; 3. Decision rules or work scheduling guidelines; 4. Improved onboard training and information; 5. Upgraded HFE requirements documents
<i>Relationship to other risks and other risk areas</i>	See other Human Behavior and Performance risks
<i>Critical Questions (priority):</i>	<p>6.09 What information management and communications systems architecture(s) and equipment will best support the crew's ability to exchange information, learn and maintain proficiency on critical tasks, and meet the objectives of a Mars mission? How will artificial intelligence or expert systems be used in these architectures? (1)</p> <p>6.10 What workload schedule(s) per workday will best enhance crew performance and mitigate adverse effects of the space environment? (2)</p> <p>6.11 What methods of assessing human performance capabilities will be most effective and useable during a Mars mission? (2)</p> <p>6.12 What factors in systems and habitat design will best enhance the crew's ability to live and work in the space environment? How are these factors different from shorter duration missions? (2)</p>
<i>Important References</i>	<p>Compton, W.D. Where no man has gone before: A history of Apollo Lunar Exploration Missions. NASA SP-4214, 1989</p> <p>Hancock, P.A., and Caird, J.K. Experimental evaluation of a model of mental workload. Human Factors, 35(3), 413-429, 1993</p> <p>Salvendy, G. Handbook of Human Factors, Second Edition. John Wiley & Sons, Inc., New York, New York, 1997</p> <p>Billings, C.E. Aviation automation: The search for a human-centered approach. Mahwah, NJ: Erlbaum, 1997</p> <p>Hollnagel, E. Reliability of cognition: Foundations of human reliability analysis. London: Academic Press, 1993</p> <p>Flight Crew Support Division Debriefs (Thagard, Lucid, Blaha, Linenger, Foale, Wolf</p>

Risk Data Sheet

<i>Risk number</i>	21
<i>Risk area</i>	Human Behavior and Performance
<i>Risk title</i>	Human Performance Failure Because of Neurobehavioral Dysfunction
<i>Contributing risk factors</i>	Behavioral Health
<i>Risk description</i>	Human performance failure due to such conditions as depression, anxiety, trauma, or other neuropsychiatric dysfunction
<i>Risk Rank</i>	4
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	4
<i>Specific current cm(s) or mitigation(s)</i>	1. Detection at the time of failure; 2. Rare opportunity for communication with crewmember
<i>Specific projected cm(s) or mitigation(s)</i>	1. Diagnostic method; 2. Computerized therapy; 3. Medication therapy; 4. Predictive model for risk of illness; 5. Individualized treatment algorithm developed preflight; 6. Holding environment for safety
<i>Relationship to other risks and to other risk areas</i>	see Overall Human Performance Risk worksheet
<i>Critical Questions (Priority):</i>	<p>6.13 What model(s) of behavioral health and task performance best predict problems and provide guidelines for effective treatment of illness (e.g., Depression, Anxiety, Trauma, Psychiatric Dysfunction)? (1)</p> <p>6.15 What are the acute and long term effects of exposure to the space environment on the processes of sensation and perception, learning, cognition, decision-making, and motor skills and how do such changes affect human performance capabilities and behavior? (2)</p> <p>6.14 What are the best countermeasures for rapidly recognizing and rapidly managing neurobehavioral dysfunction, emotional and stress-related dysfunction, neuropsychiatric dysfunction, and social psychological dysfunction, and how does the spaceflight environment affect their implementation? (1)</p> <p>6.16 What are the acute and long term effects of exposure to other space environment (microgravity, isolation, stress) on the nervous system (at the cellular, molecular, or organismic levels) and on related neurobehavioral mechanisms, including neurobiology related to behavior and mood regulation? (2)</p> <p>6.19 What are the acute and long term effects of exposure to the space environment on human emotion and psychological responses, including emotional reactivity, stress responses, long term modulation of mood, and vulnerability to affective disorders? (NR)</p> <p>6.20 What are the best methods of inflight monitoring for neurobehavioral dysfunction, including cognitive and performance dysfunction, emotional and stress-related dysfunction, neuropsychiatric dysfunction, and social psychological dysfunction? (NR)</p>
<i>Important References</i>	<p>Gunderson, E.K.E. Mental Problems in Antarctica, Arch. of Environmental Health, 17: 558-564, 1968</p> <p>Matusov, Anatoly. Morbidity Among Members of the 10th Soviet Antarctic Expedition, Soviet Antarctic Expedition, 38-256, 1968</p> <p>Diagnostic and Statistical Manual of Mental Disorders, 1994 <i>need complete reference</i></p> <p>Mintz, J., Mintz, L.I., Arruda, M.J., Hwang, S.S. Treatments of Depression and the Functional Capacity to Work, Archives of General Psychiatry, Vol. 49, October, 1992</p>

7.0 Immunology, Infection and Hematology

Risk Data Sheet

<i>Risk number</i>	22
<i>Risk area</i>	Immunology, Infection and Hematology
<i>Risk title</i>	Immunodeficiency/Infections
<i>Contributing risk factors</i>	Stress; Radiation exposure; Decreased cell function; Altered environmental exposure
<i>Risk description</i>	Increased risk of infection due to: (1) impaired immune response (stress, radiation, decreased cell function); (2) altered environmental exposure; (3) persistent viruses or the reactivation of viruses
<i>Risk Rank (within risk area)</i>	1
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	4
<i>Specific current cms</i>	Pre-flight Quarantine (Health Stabilization Program)
<i>Specific projected cms</i>	Immunizations, immune system activators, viral suppression agents, environmental monitoring
<i>Relationship to other risks and to other risk areas)</i>	Radiation Effects, Environmental Health, Food and Nutrition, Sleep and Circadian Rhythm Problems, Human Behavior and Performance
<i>Critical Questions:</i>	<p>7.01 Are there assays of immune function that reliably predict immune compromise? (2)</p> <p>7.03 Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)? (1)</p> <p>7.10 Does the change in fluid distribution away from the extremities affect microcirculation in peripheral tissues, and does this represent a risk to the crew (wound healing, lymphocyte migration, immune surveillance)? (1)</p> <p>7.11 Does the spacecraft environment exert a selective pressure on environmental microorganisms which presents the crew with increased health risks (e.g. heliobacteria and ulcers)? (2)</p> <p>7.13 What diagnostic and environmental monitoring laboratory technologies need to be developed for the detection and diagnosis of infectious disease in microgravity? (3)</p> <p>7.17 Which potentially infectious agents will crewmembers be exposed to and what are their sources? (2)</p> <p>7.20 Does the loss of blood volume in spaceflight affect immune surveillance? (1)</p> <p>7.21 Does the alteration of sleep wake cycles produce alterations in chronobiology of immune responses due to upsetting the neuroendocrine axis and producing stress? (NR)</p> <p>7.22 Are there countermeasures for spaceflight-associated defects in antibody, T-cell, phagocyte, and compliment systems? (NR)</p> <p>7.23 Are there countermeasures for infections developed in space travel, especially latent virus infections? (NR)</p> <p>7.25 Are there deficiencies of diet or micronutrients in long term space travel that would negatively impact on the CD4⁺ T-Cell population and produce immunosuppression? (NR)</p> <p>7.26 Are there diet supplements or additives that could restore a malnutrition-induced state of immunosuppression? (NR)</p> <p>7.27 Can medical records of astronauts be obtained for epidemiological study of long term adverse health consequences of space travel (e.g., immunodeficiency, chronic viral infections, malignancy, hypersensitivity and allergy)? (NR)</p> <p>7.28 Do conditions of mechanical forces of space travel disrupt cytokine: cytokine receptor signal transmissions in immune cells? (NR)</p> <p>7.29 Are there surrogate marker essays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and implement function? (NR)</p> <p>7.04 Do factors associated with spaceflight increase reactivation of latent viruses? (2)</p>
<i>Important References</i>	<p>Tipton, CM, Greenlead, JE, Jackson, CG: Neuroendocrine and immune system responses with spaceflights. <i>Med Sci Sports Exerc</i> 28:988-98, 1996.</p> <p>J Leukocyte Bio 54:179-268, 1993.</p> <p>Sandberg, ET., Kline, MW., Shearer, WT. The Secondary Immunodeficiencies. In Stichm, ER., (Ed). Immunologic Disorders in Infants and Children. 4th Edition. Philadelphia: WB Saunders, pp. 553-602, 1996</p> <p>Noroski, LM, Shearer, WT. <i>Short Analytical Review: Screening for Primary Immunodeficiencies in the Clinical Laboratory. Clin Immunol Immunopath</i>; 86: 237-245, 1998.</p> <p>Grady, D. <i>Trapped at the South Pole, Doctor Becomes a Patient. New York Times, July 13: 1, 15, 1999.</i></p>

Risk Data Sheet

<i>Risk number</i>	23
<i>Risk area</i>	Immunology, Infection and Hematology
<i>Risk title</i>	Carcinogenesis Caused by Immune System Changes
<i>Contributing risk factors</i>	Radiation exposure; Chemical exposure; Viruses
<i>Risk description</i>	Increased risk due to: (1) increased oncogene expression (radiation induced or altered cell function); (2) decreased immune system surveillance; (3) reactivated viruses
<i>Risk Rank (within risk area)</i>	1
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	4
<i>Specific current cms</i>	Not specified
<i>Specific projected cms</i>	Immune system activators, viral suppression agents
<i>Relationship to other risks within risk area and to other risk areas</i>	Dependent on countermeasures or mitigations of Radiation Effects risk area
<i>Critical Questions:</i>	7.03 Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)? (1)
	7.01 Are there assays of immune function that reliably predict immune compromise? (2)
	7.04 Do factors associated with spaceflight increase reactivation of latent tumor viruses? (2)
	7.15 Which oncogenic mechanisms may be activated by in-flight radiation exposure? (2)
	7.18 What diagnostic and treatment capabilities are required for radiation induced illness? (3)
	7.14 What is the risk of cancer during or following long duration spaceflight? (1)
	7.29 Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function? (NR)
	7.24 Are there countermeasures for development of malignancy in space travel? (NR)
	7.21 Does the alteration of sleep wake cycles produce alterations in chronobiology of immune responses due to upsetting the neuroendocrine axis and producing stress? (NR)
	7.30 Does the change in fluid distribution affect microcirculation in peripheral tissues, and does this alter lymphocyte migration or immune surveillance)? (2)
<i>Important References::</i>	James JT: Carcinogens in spacecraft air. <i>Radiat Res</i> 148 (5 Suppl):11-16, 1997
	<i>J Leukocyte Bio</i> 54:179-268, 1993.

Risk Data Sheet

<i>Risk number</i>	24
<i>Risk area</i>	Immunology, Infection and Hematology
<i>Risk title</i>	Altered hemodynamic and cardiovascular dynamics caused by changes in blood components
<i>Contributing risk factors</i>	Loss of plasma and red blood cells due to exposure to microgravity
<i>Risk description</i>	Plasma volume decreases up to 25% during first 24 hours in space; there is a decrease of RBCM of 15% in the first week in space (2 units of blood); 15% loss of effective blood volume in the seven minutes preceding landing; aerobic capacity reduced due to decrease in RBCM; decrease in blood volume in bone and muscle may contribute to dysfunction of crew. This can be a severe risk to the mission for several hours and can have significant impact on the crew relating to rapid egress from the spacecraft.
<i>Risk Priority (within risk area)</i>	1
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or mitigation(s)</i>	Erythropoietin
<i>Specific projected countermeasure(s) or mitigation(s)</i>	In-flight monitoring of hematological parameters, Hematopoiesis inducing agents, replacement of blood volume, use of artificial gravity to prevent volume losses
<i>Relationship to other risks, risk areas</i>	
<i>Critical Questions:</i>	<p>7.12 Does anemia following spaceflight diminish the aerobic capacity of individuals entering a gravitational environment or represent a risk to crewmembers on landing? (2)</p> <p>7.02 Can the physiologic mechanisms responsible for hematopoiesis be influenced to increase red cell mass? (NR)</p> <p>7.20 Does the loss of blood volume in spaceflight affect immune surveillance? (1)</p> <p>7.03 Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, non-specific immunity, mucosal immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)? (1)</p> <p>7.29 Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function? (NR)</p> <p>7.31 Does the change in fluid distribution away from the extremities affect microcirculation in peripheral tissues, and does this represent a cardiovascular, muscle, or bone risk to the crew? (1)</p>
<i>Important References</i>	<p>Alfrey, CP, Udden, MM, Leach-Huntoon, C, Driscoll, T, Pickett, MH: Control of red blood cell mass in spaceflight. <i>J Appl Physiol</i> 81:98-104, 1996.</p> <p>Davis, TA, Wiesmann, W, Kidwell, W, Cannon, T, Kerns, L, Serke, C, Delaplaine, T, Pranger, A, Lee, KP: Effect of spaceflight on human stem cell hematopoiesis: suppression of erythropoiesis and myelopoiesis. <i>J Leukoc Biol</i> 60:69-76, 1996.</p> <p>Udden, MM, Driscoll, TB, Pickett, MH, Leach-Huntoon, CS, Alfrey, CP: Decreased production of red blood cells in human subjects exposed to microgravity. <i>J Lab Clin Med</i> 125:442-9, 1995.</p> <p>SLS1 and SLS2 Final Report</p> <p><i>Journal of Applied Physiology</i>, 81: 90-104, 1996</p> <p><i>Journal of Applied Physiology</i>, 81: 105-116, 1996</p> <p><i>Med. Sci. Sports Exercise</i>, 28: 542-544, 1996</p> <p><i>Med. Sci. Sports Exercise</i>, 28: 545-552, 1996.</p>

Risk Data Sheet

<i>Risk number</i>	25
<i>Risk area</i>	Immunology, Infection and Hematology
<i>Risk title</i>	Altered wound healing
<i>Contributing risk factors</i>	Not specified
<i>Risk description</i>	Decreased immune response due to altered immune cell function or tissue localization/transport
<i>Risk Rank (within risk area)</i>	2
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	Not specified
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Antiseptic treatments, wound healing promoters
<i>Relationship to other risks within risk area and to other risk areas</i>	
<i>Critical Questions:</i>	7.03 Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)? (1)
	7.16 Which compounds can be used as effective promoters of wound healing? (3)
	7.01 Are there assays of immune function that reliably predict immune compromise? (2)
	7.29 Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function? (NR)
	7.32 Does the change in fluid distribution away from the extremities affect microcirculation in peripheral tissues, and does this represent a risk to the crew (wound healing, lymphocyte migration, immune surveillance)? (2)
<i>Important References</i>	<i>J Leukocyte Bio</i> 54:179-268, 1993.

Risk Data Sheet

<i>Risk number</i>	26
<i>Risk area</i>	Immunology, Infection and Hematology
<i>Risk title</i>	Altered host - microbial interactions
<i>Contributing risk factors</i>	Spacecraft environmental factors; Host defense factors; Nutrition
<i>Risk description</i>	Changes in microflora; alterations in host susceptibility; genetic change/mutation of microorganisms
<i>Risk Rank (within risk area)</i>	3
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or mitigation(s)</i>	In-flight environmental monitoring and bioburden reduction procedures.
<i>Specific projected countermeasure(s) or mitigation(s)</i>	In-flight antibiotic susceptibility testing capability; Preflight screening; In-flight microbial identification capability.
<i>Relationship to other risks/risk areas</i>	Dependent on Environmental Microbiology monitoring and mitigations.
<i>Critical Questions:</i>	7.13 What diagnostic and environmental monitoring laboratory technologies need to be developed for the detection and diagnosis of infectious disease in space? (3)
	7.11 Does the spacecraft environment exert a selective pressure on environmental microorganisms which presents the crew with increased health risks (e.g., heliobacteria and ulcers)? (2)
	7.06 Does spaceflight alter microbial growth rates, mutation rates, or pathogenicity? (2)
	7.09 Does spaceflight alter the exchange of genetic material between microorganisms? (2)
	7.23 Are there countermeasures for infections developed in space travel, especially latent virus infections? (NR)
	7.19 Does spaceflight alter host-microbe balance? (2)
<i>Important References:</i>	Not Specified

Risk Data Sheet

<i>Risk number</i>	17
<i>Risk area</i>	Immunology, Infection and Hematology
<i>Risk title</i>	Allergies and hypersensitivity reactions
<i>Contributing risk factors</i>	Exposure to environmental agents (chemical/biological); autoimmune disease
<i>Risk description</i>	Increased risk due to: (1) autoimmune disease from inappropriate response by immune system; (2) allergic hypersensitivity; (3) exposure to environmental (chemical/biological) agents
<i>Risk Rank (within risk area)</i>	3
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or mitigation(s)</i>	Toxicological/Environmental/Microbiological standards for spacecraft atmosphere.
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Environmental control, immunizations/allergy therapy, immune system activators, viral suppression agents
<i>Relationship to other risks within risk area and to other risk areas</i>	Environmental Health
<i>Critical Questions:</i>	7.03 Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)? (1)
	7.01 Are there assays of immune function that reliably predict immune compromise? (2)
	7.29 Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function? (NR)
	7.23 Are there countermeasures for infections developed in space travel, especially latent virus infections? (NR)
	7.05 Do unique environmental factors inside the spacecraft promote transmission of microbial pathogens, or cause increased risk of infection, allergy or hypersensitivity reactions independent of altered immune function? (2)
<i>Important References:</i>	Tipton, CM, Greenlead, JE, Jackson, CG: Neuroendocrine and immune system responses with spaceflights. <i>Med Sci Sports Exerc</i> 28:988-98, 1996.
	<i>J Leukocyte Bio</i> 54:179-268, 1993.

8.0 Muscle Alterations and Atrophy

Risk Data Sheet

<i>Risk number</i>	28
<i>Risk area</i>	Muscle Alterations and Atrophy
<i>Risk title</i>	Loss of skeletal muscle mass, strength and/or endurance
<i>Contributing risk factors</i>	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)
<i>Risk description</i>	The inability to perform emergency egress, landing and in partial gravity due to significant losses of muscle mass, strength and/or endurance. Such reduction would affect the ability to perform emergency egress, movements required for landing in partial gravity (fine motor control) and piloting prior to landing.
<i>Risk Rank (within risk area)</i>	1
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	heavy resistive exercise, treadmill (continuous and interval running); cycle ergometry; rower ergometry
<i>Specific projected countermeasure(s) or mitigation(s)</i>	heavy resistive exercise, treadmill (continuous and interval running); cycle ergometry; rower ergometry (using higher technology equipment and more intense exercise and greater exercise duration in time and days); pharmacological/hormonal interventions
<i>Relationship to other risks within risk area and to other risk areas</i>	cardiovascular alterations, neurovestibular adaptation, bone loss, human performance, space medicine, immunology, infection and hematology, food and nutrition, environmental health, advanced life support
<i>Critical Questions:</i>	8.01 What are the appropriate prescription modalities and the compliance factors needed to minimize losses in muscle mass, strength and endurance, and facilitate rehabilitation? (1)
	8.02 To what extent should hormonal/pharmacological supplements be used as a countermeasure if exercise regimens are ineffective in maintaining homeostasis? (1)
	8.08 What are the appropriate exercise modalities and prescriptions needed to optimize skeletal muscle performance? (1)
	8.09 How do muscle cells sense the mechanical stress of gravity? (1)
	8.03 What is the role of, and what is necessary in order to establish the hormonal profile of astronauts during long duration spaceflight? (1)
<i>Important References:</i>	NASA, Space Life Sciences, Final Report Task Force on Countermeasures, (Chair, Kenneth M. Baldwin) May 1997

Risk Data Sheet

<i>Risk number</i>	29
<i>Risk area</i>	Muscle Alterations and Atrophy
<i>Risk title</i>	Inability to adequately perform tasks due to motor performance, muscle endurance and disruption in the structural and functional properties of the soft and hard connective tissues of the axial skeleton
<i>Contributing risk factors</i>	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)
<i>Risk description</i>	Inability to perform a variety of tasks associated with microgravity EVA, IVA and daily activities due to motor performance, muscle endurance and disruptions in the structural and functional properties (including phenotype) of the soft and hard connective tissues of the axial skeleton (i.e. intervertebral disk, lower back syndrome)
<i>Risk Rank (within risk area)</i>	I
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	preflight regularly scheduled (6X week) crew physical training; heavy resistive exercise; treadmill (continuous and interval running); and cycle and rower ergometry
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Individually tailored crew fitness training program preflight; heavy resistive exercise, treadmill (continuous and interval running); and cycle and rower ergometry (using higher technology equipment, more intense exercise, and greater exercise duration in time and days); pharmacological/hormonal interventions
<i>Relationship to other risks within risk area and to other risk areas</i>	Bone loss, cardiovascular alterations, neurovestibular adaptation, human performance, space medicine, immunology, infection and hematology, food and nutrition, environmental health, advanced life support
<i>Critical Questions:</i>	8.01 What are the appropriate prescription modalities and the compliance factors needed to minimize losses in muscle mass, strength and endurance? (1)
	8.02 To what extent should hormonal/pharmacological supplements be used as a countermeasure if exercise regimens are ineffective in maintaining homeostasis? (1)
	8.08 What are the appropriate exercise modalities and prescriptions needed to optimize skeletal muscle performance? (1)
	8.03 What is the role of, and what is necessary in order to establish the hormonal profile of astronauts during long duration spaceflight? (1)
<i>Important References:</i>	NASA, Space Life Sciences, Final Report Task Force on Countermeasures, (Chair, Kenneth M. Baldwin) May 1997

Risk Data Sheet

<i>Risk number</i>	30
<i>Risk area</i>	Muscle Alterations and Atrophy
<i>Risk title</i>	Inability to sustain muscle performance levels to meet demands of performing activities of varying intensities
<i>Contributing risk factors</i>	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)
<i>Risk description</i>	The inability to sustain muscle performance levels to meet the demands of performing mission-specific activities of varying intensities. Included in this risk are that deficits will exist in the maintenance of gait and posture that are required to complete these activities. An additional concern is that sufficient nutritional provisions may not be available to provide the necessary substrate energy to complete these tasks.
<i>Risk Rank (within risk area)</i>	2
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	preflight fitness training and inflight exercise countermeasures
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Ground-based exercise countermeasures on Martian surface for physiological improvements for surface tasks and return to Earth
<i>Relationship to other risks within risk area and to other risk areas</i>	Food and nutrition, neurovestibular adaptations, bone loss, cardiovascular alterations, neurovestibular adaptation, human performance, space medicine, immunology, infection and hematology, environmental health, advanced life support
<i>Critical Questions:</i>	8.04 What effect does long term spaceflight/operational countermeasures have on nitrogen balance (i.e., anabolic/catabolic control of protein expression)? (1) 8.05 What are the effects of long term spaceflight on the metabolism of carbohydrates and fats, and what is their influence on sustained aerobic work and performance? (1)
<i>Important References:</i>	NASA, Space Life Sciences, Final Report Task Force on Countermeasures, (Chair, Kenneth M. Baldwin) May 1997

Risk Data Sheet

<i>Risk number</i>	31
<i>Risk area</i>	Muscle Alterations and Atrophy
<i>Risk title</i>	Propensity to develop muscle injury, connective tissue dysfunction, and bone fractures due to deficiencies in motor skill, muscle strength and muscular fatigue
<i>Contributing risk factors</i>	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance
<i>Risk description</i>	Propensity to develop muscle injury, connective tissue dysfunction, and bone fractures due to deficiencies in motor skill, muscle strength, and muscular fatigue.
<i>Risk Rank (within risk area)</i>	3
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	preflight fitness training (6X week) and inflight exercise countermeasures; heavy resistive exercise; treadmill (continuous and interval running); and cycle and rower ergometry
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Ground-based exercise countermeasures on Martian surface for physiological improvements for surface tasks and return to Earth ; Individually tailored crew fitness training program preflight; heavy resistive exercise, treadmill (continuous and interval running); and cycle and rower ergometry (using higher technology equipment, more intense exercise, and greater exercise duration in time and days); pharmacological/hormonal interventions
<i>Relationship to other risks within risk area and to other risk areas</i>	Food and nutrition, neurovestibular adaptations, bone loss, cardiovascular alterations, neurovestibular adaptation, human performance, space medicine, immunology, infection and hematology, environmental health, advanced life support
<i>Critical Questions:</i>	8.06 Do the deficits in skeletal muscle associated with long duration spaceflight affect the structural/functional properties of the sensory system and motor nerves? Describe the muscle tendon interface. (1)
	8.07 Do structural and functional deficits in the skeletal muscle system associated with long duration spaceflight impact: neurovestibular homeostasis; cardiovascular deconditioning; deficits in bone (regional and general); the muscle and tendon interface, and feedback from the skeletal muscle to the central nervous system (hypothalamus, hypophysis)? (1)
<i>Important References:</i>	NASA, Space Life Sciences, Final Report Task Force on Countermeasures, (Chair, Kenneth M. Baldwin) May 1997

Risk Data Sheet

<i>Risk number</i>	32
<i>Risk area</i>	Muscle Alterations and Atrophy
<i>Risk title</i>	Impact of deficits in skeletal muscle structure and function on other systems
<i>Contributing risk factors</i>	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)
<i>Risk description</i>	Deficits in skeletal muscle structure and function can impact the homeostasis of other systems including: neurovestibular/motor performance; vascular compliance and circulatory function impacting blood pressure regulation (e.g., skeletal muscle pump); soft and hard connective tissue integrity (e.g., tendon, bone, cartilage) and local versus general (e.g., tendon-bone interaction); radiation may alter the proliferation of muscle (satellite cell s) and bone forming cells (osteoblasts) which may alter the ability of these tissues to regenerate/repair; inadequate nutritional support may result in insufficient substrate energy and protein balance required for normal muscle performance.
<i>Risk Rank (within risk area)</i>	Not rated (NR)*
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	NR
<i>Specific current countermeasure(s) or mitigation(s)</i>	preflight fitness training (6X week) and inflight exercise countermeasures; heavy resistive exercise; treadmill (continuous and interval running); and cycle and rower ergometry
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Ground-based exercise countermeasures on Martian surface for physiological improvements for surface tasks and return to Earth ; Individually tailored crew fitness training program preflight; heavy resistive exercise, treadmill (continuous and interval running); and cycle and rower ergometry (using higher technology equipment, more intense exercise, and greater exercise duration in time and days); pharmacological/hormonal interventions
<i>Relationship to other risks within risk area and to other risk areas</i>	Cardiovascular alterations, radiation effects, food and nutrition, bone loss, neurovestibular adaptation
<i>Critical Questions:</i>	8.06 Do the deficits in skeletal muscle associated with long duration spaceflight affect the structural/functional properties of the sensory and motor nerves? Describe the muscle tendon interface. (1)
	8.07 Do structural and functional deficits in the skeletal muscle system associated with long duration spaceflight impact: neurovestibular homeostasis; cardiovascular deconditioning; deficits in bone (regional and general); the muscle and tendon interface, and feedback from the skeletal muscle to the central nervous system (hypothalamus, hypophysis)? (1)
<i>Important References:</i>	NASA, Space Life Sciences, Final Report Task Force on Countermeasures, (Chair, Kenneth M. Baldwin) May 1997

*NR: not currently rated by risk area team

9.0 Neurovestibular Adaptation

Risk Data Sheet

<i>Risk number</i>	33
<i>Risk area</i>	Neurovestibular Adaptation
<i>Risk title</i>	Disorientation and Inability to Perform Landing, Egress, or Other Physical Tasks, Especially During/After G-level Changes (Acute spontaneous & provoked vertigo, nystagmus, oscillopsia, poor dynamic visual acuity)
<i>Contributing risk factors</i>	Sleep disorders; Sleep disruption; Circadian dysrhythmia; Impaired cognitive or psychomotor performance; Space motion sickness
<i>Risk description</i>	Spatial disorientation, sensory illusions and motor performance problems involving locomotion and posture often accompany exposure to a new and different gravitational field. These adaptations are usually transient in nature but can adversely impact cognitive performance and motor skills during emergency egress procedures, or may result in the inability to complete a Mars landing phase manual re-entry. Any significant duration or magnitude of gravitoinertial forces will affect any other critical performance. Countermeasure would be totally automated landing system.
<i>Risk Rank (within risk area)</i>	I
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	2
<i>Specific current countermeasure(s) or mitigation(s)</i>	Exercise regimes
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Resistive exercise, Martian surface with 1/3 G
<i>Relationship to other risks and to other risk areas</i>	Human Behavior and Performance
<i>Critical Questions (priority):</i>	<p>9.01 What are the pros and cons of artificial gravity (AG) as a countermeasure? What are the advantages and disadvantages of large radius continuous AG vs. short radius, intermittent AG? (1)</p> <p>9.02 What are the appropriate ground-based spaceflight analog environments that can be used as test beds for evaluating neurological adaptation time constants, adverse operational implications, countermeasures, and impacts of adaptation on other anatomical and physiological systems? (2)</p> <p>9.03 How do altered time constants associated with neurological (sensorimotor, autonomic, emetic) adaptation to spaceflight (microgravity and 1/3 Mars surface) correlate with physiological and operational performance changes? (3)</p> <p>9.04 How do countermeasures (e.g., artificial gravity, inflight exercise, or preflight training) affect adaptation time constraints? (3)</p> <p>9.05 How do the large inter-individual differences in response to altered magnitude and duration of gravito-inertial forces (weightlessness and return to Earth) correlate with physiological and operational performance changes? (3)</p> <p>9.08 How do visual, vestibular and haptic cues contribute to inversion illusions, visual reorientation, illusions, EVA acrophobia, disorientation and poor 3D spatial memory problems in 0-G? (2)</p> <p>9.09 What is the physiological basis of inversion illusions, visual reorientation, and 3D memory problems in 0-G? (2)</p> <p>9.10 Can preflight training techniques (e.g. virtual reality simulations) be used to alleviate these problems, and to evaluate emergency procedures? (2)</p> <p>9.25 What is the physiological basis for oscillopsia, disorientation, and reduced dynamic visual acuity reported by crewmembers making head movements during re-entry? (2)</p> <p>9.27 How can 0-G immersive teleoperation displays be designed to reduce disorientation and/or motion sickness? (2)</p>
<i>Key References</i>	Not Specified

Risk Data Sheet

<i>Risk number</i>	34
<i>Risk area</i>	Neurovestibular Adaptation
<i>Risk title</i>	Impaired Neuromuscular Coordination and/or Strength (Gait ataxia, postural instability)
<i>Contributing risk factors</i>	Sleep disorders; Sleep disruption, Circadian dysrhythmia; Impaired cognitive or psychomotor performance; Space motion sickness
<i>Risk description</i>	Impaired neuromuscular strength upon return to positive G leading to increased occurrence of falls and fractures during emergency egress and escape
<i>Risk Rank (within risk area)</i>	2
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or mitigation(s)</i>	Resistive exercise regimes
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Artificial gravity
<i>Relationship to other risks within risk area and to other risk areas</i>	Human Behavior and Performance
<i>Critical Questions (priority):</i>	9.01 What are the tradeoffs of artificial gravity as a countermeasure for neurovestibular deficits? What are the risks/benefits of long-arm continuous versus short-arm, within-craft, intermittent artificial gravity countermeasures? (1)
	9.02 What are the appropriate ground-based spaceflight analog environments that can be used as test beds for evaluating neurological adaptation time constraints, adverse operational implications, countermeasures, and impacts of adaptation on other anatomical and physiological systems? (2)
	9.04 How do countermeasures (e.g., artificial gravity, inflight exercise, or preflight training) affect adaptation time constraints? (3)
	9.05 How do the large inter-individual differences in response to altered magnitude and duration of gravito-inertial forces (weightlessness and return to Earth) correlate with physiological and operational performance changes? (3)
	9.22 What is the relative contribution of neurovestibular adaptation, neuromuscular deconditioning, and orthostatic intolerance to postflight neuromuscular coordination, ataxia, and locomotion difficulties? (3)
	9.24 Can preflight or inflight training, or sensory aids and prostheses, improve postlanding postural and locomotor control? (2)
<i>Key References:</i>	Not Specified

Risk Data Sheet

<i>Risk number</i>	35
<i>Risk area</i>	Neurovestibular Adaptation
<i>Risk title</i>	Impaired Cognitive and/or Physical Performance Due to Motion Sickness Symptoms or Treatments, Especially During/After G-level Changes (Including short term memory loss, reaction time increase, drowsiness, fatigue, torpor, irritability, ketosis)
<i>Contributing risk factors</i>	Change in gravity levels
<i>Risk description</i>	Any change in gravitoinertial forces can result in SMS (nausea, disorientation, dizziness, vomiting, and loss of appetite, drowsiness) and could degrade performance. Only countermeasure/risk mitigations currently available are drugs that are showing to have undesirable side effects. Continued concern is based on Russian observation that 94% of returning long duration crews still experience motion sickness after standing.
<i>Risk Rank (within risk area)</i>	3
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or mitigation(s)</i>	Promethazine; Controlled head movements during take-off and landing; Pre-adaptation training (PAT) in simulated environments; Restricted head movements
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Antimotion Sickness Medication; Artificial G
<i>Relationship to other risks within risk area and to other risk areas</i>	Clinical Capabilities, Human Behavior and Performance
<i>Critical Questions (priority):</i>	9.11 What physical and cognitive performance will be required of the crew during the acceleration/deceleration portions of the mission? (2)
	9.12 How effective is promethazine injection (or other drugs) in providing fast relief in mission critical situations? Does the drug have unacceptable side effects, particularly the short-term effects on cognitive function? (1)
	9.23 To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness? (2)
	9.26 What is the physiological basis of space motion sickness? How does chronic space motion sickness (including space adaptation syndrome) affect mood, initiative, and interpersonal relationships? (2)
	9.27 How can 0-G immersive teleoperation displays be designed to reduce disorientation and/or motion sickness? (2)
<i>Important References:</i>	Not Specified

Risk Data Sheet

<i>Risk number</i>	36
<i>Risk area</i>	Neurovestibular Adaptation
<i>Risk title</i>	Vestibular Contribution to Cardiorespiratory Dysfunction (Postlanding orthostatic intolerance, sleep and mood changes)
<i>Contributing risk factors</i>	Return to 1 G
<i>Risk description</i>	On return to positive gravity environment, vestibular interaction with autonomic system leads to syncope
<i>Risk Priority (within risk area)</i>	4
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	Pre-adaptation training, exercise
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Fully autonomic landing system; Inflight Landing Control Practice; Preflight egress training, Crew station design; Resistive exercise
<i>Relationship to other risks and to other risk areas</i>	Cardiovascular Alterations; Muscle Alterations and Atrophy
<i>Critical Questions:</i>	9.15 Does neurovestibular adaptation to weightlessness impair postlanding cardiovascular regulation and contribute to orthostatic intolerance? (1)
	9.16 Do vestibular countermeasures improve postlanding cardiovascular regulation and orthostatic tolerance? (1)
	9.17 How does neurovestibular adaptation contribute to postlanding postural control and locomotion difficulties? (2)
	9.22 What is the relative contribution of neurovestibular adaptation, neuromuscular deconditioning, and orthostatic intolerance to postflight neuromuscular coordination, ataxia and locomotion difficulties? (2)
	9.23 To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness? (2)
<i>Important References:</i>	Not specified

Risk Data Sheet

<i>Risk number</i>	37
<i>Risk area</i>	Neurovestibular Adaptation
<i>Risk title</i>	Possible Chronic Impairment of Orientation or Balance Function Due to Microgravity or Radiation (Imbalance, gait ataxia, vertigo, chronic vestibular insufficiency, poor dynamic visual acuity)
<i>Contributing risk factors</i>	Radiation exposure; Prolonged exposure to microgravity
<i>Risk description</i>	Prolonged exposure (or successful adaptation) to an altered gravitational environment may result in irreversible changes in neurological structure and function and can lead to performance decline, poor morale and shift to early return scenario.
<i>Risk Rank (within risk area)</i>	5
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	None
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Not specified
<i>Relationship to other risks within risk area and to other risk areas</i>	Muscle Alterations and Atrophy, Clinical Capabilities, Human Behavior and Performance
<i>Critical Questions:</i>	9.20 What are the significant irreversible changes in sensory-motor neurological function associated physiological systems, and anatomical and/or biochemical processes that may be caused by exposure or development in long duration 0-G or partial -G and what are the mechanisms and time course? (4)
	9.21 How can these changes be optimally distinguished from the normal responses to stress, isolation, and normal background physiological variability? What countermeasures can be developed? (4)
	9.24 Can preflight training or inflight training, or sensory aids and prostheses, improve postlanding and locomotor control? (2)
<i>Important References:</i>	Not Specified

10.0 Radiation Effects

Risk Data Sheet

<i>Risk number</i>	38
<i>Risk area</i>	Radiation Effects
<i>Risk title</i>	Carcinogenesis Caused by Radiation
<i>Contributing risk factors</i>	Genetic susceptibility; Nutrition; Immune function; Growth factors; Stress; Environmental mutagens; Age; Gender
<i>Risk description</i>	Ionizing radiation can effectively induce various types of tumors in humans as both an initiator and promotor. Except leukemia, which has relatively short latency period, solid tumors usually take more than ten years to develop after irradiation.
<i>Risk Rank (within risk area)</i>	1
<i>Risk Type (across risks)</i>	I
<i>Current risk mitigation status</i>	4
<i>Specific current countermeasure(s) or mitigation(s)</i>	bone marrow transplantation, nutrition, antibiotics, growth factors, spacecraft shielding, body shielding, active dose rate monitors, passive crew dosimeters, biodosimetry, dose management, ground solar particle event warning system
<i>Specific projected countermeasure(s) or mitigation(s)</i>	genetic screening for individual sensitivity, chemical radioprotectants with minimum side effects, cancer progression inhibitors, biological markers for space radiation damage in cells, biophysical computer models for accurate health risk assessment, active neutron spectrometer, active soft x-ray detector for solar particle events, new shielding materials and methods
<i>Relationship to other risks within risk area and to other risk areas</i>	Immunology, Infections and Hematology
<i>Critical Questions:</i>	10.09 What are the cancer risks in humans from spaceflight? (1)
	10.11 What is the acceptable accuracy for risks of acute and late effects in humans from photons to adequately extrapolate to space? (1)
	10.05 Are there unique biological effects associated with HZE's? (1)
	10.06 Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties? (2)
	10.07 How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation? (1)
	10.01 Are the biological effects for protons above 10 MeV sufficiently similar to photons that photon data can be used for their consequences? (3)
	10.10 What are the risks from SPE's and what is their impact on operations, EVAs and surface exploration? (1)
	10.04 Are there differences in response to particles with similar LET, but with different atomic numbers and energies? (2)
	10.12 What are the effects of age, gender, and inter-individual diversity? (2)
	10.08 How do the thickness, design, and material composition of space vehicles affect the internal radiation environment and biological assessment? (1)
	10.03 Are there chemopreventive or biological agents which would mitigate acute or late effects? (3)
	NCRP Report No. 98 "Guidance on Radiation Received in Space Activities" (1989)
<i>Important References:</i>	NRC Report "Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies" (1997)
	International Commission on Radiological Protection (ICRP) Report 60 "Recommendations of the International Commission on Radiological Protection" (1990)
	Robbins, D. E. and T. C. Yang (1994) Chapter 9. Radiation and Radiobiology. In: Space Physiology and Medicine. Ed. A. E. Nicogossian, C. L. Huntoon, and S. L. Pool. Lea & Febiger, Philadelphia, PA

Risk Data Sheet

<i>Risk number</i>	39
<i>Risk area</i>	Radiation Effects
<i>Risk title</i>	Damage to central nervous system from radiation exposure
<i>Contributing risk factors</i>	Genetic susceptibility; Extracellular milieu; Environmental toxic agents
<i>Risk description</i>	Ionizing radiation can damage cells in central nervous system, such as glial cells and neurons. The effectiveness of space radiation, particularly heavy charged particles with high linear energy transfer, in damaging central nervous system is not well known, but is expected to be very high.
<i>Risk Rank (within risk area)</i>	2
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	bone marrow transplantation, nutrition, antibiotics, growth factors, spacecraft shielding, body shielding, active dose rate monitors, passive crew dosimeters, biodosimetry, dose management, ground solar particle event warning system
<i>Specific projected countermeasure(s) or mitigation(s)</i>	genetic screening for individual sensitivity, chemical radioprotectants with minimum side effects, cancer progression inhibitors, biological markers for space radiation damage in cells, biophysical computer models for accurate health risk assessment, active neutron spectrometer, active soft x-ray detector for solar particle events, new shielding materials and methods
<i>Relationship to other risks within risk area and to other risk areas</i>	
<i>Critical Questions:</i>	10.11 What is the acceptable accuracy for risks of acute and late effects in humans from photons to adequately extrapolate to space? (2)
	10.05 Are there unique biological effects associated with HZE's? (1)
	10.06 Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties? (3)
	10.07 How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation? (1)
	10.01 Are the biological effects for protons above 10 MeV sufficiently similar to photons that photon data can be used for their consequences? (3)
	10.10 What are the risks from SPE's and what is their impact on operations, EVAs and surface exploration? (1)
	10.04 Are there differences in response to particles with similar LET, but with different atomic numbers and energies? (2)
	10.12 What are the effects of age, gender, and inter-individual diversity? (2)
	10.08 How do the thickness, design, and material composition of space vehicles affect the internal radiation environment and biological assessment? (1)
<i>Important References:</i>	10.03 Are there chemopreventive or biological agents which would mitigate acute or late effects? (3)
	NCRP Report No. 98 "Guidance on Radiation Received in Space Activities" (1989)
	NRC Report "Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies" (1997)
	International Commission on Radiological Protection (ICRP) Report 60 "Recommendations of the International Commission on Radiological Protection" (1990)
	Robbins, D. E. and T. C. Yang (1994) Chapter 9. Radiation and Radiobiology. In: Space Physiology and Medicine. Ed. A. E. Nicogossian, C. L. Huntoon, and S. L. Pool. Lea & Febiger, Philadelphia, PA

Risk Data Sheet

<i>Risk number</i>	40
<i>Risk area</i>	Radiation Effects
<i>Risk title</i>	Synergistic effects from exposure to radiation, microgravity, and other spacecraft environmental factors
<i>Contributing risk factors</i>	Microgravity or weightlessness; Genetic susceptibility; Environmental cytotoxic and mutagenic compounds
<i>Risk description</i>	Cellular responses to ionizing radiation can be modified directly or indirectly by other environmental factors, such as weightlessness and cytotoxic compounds present in the spacecraft. The total biological effects of radiation and another environmental factor can be more than additive.
<i>Risk Rank (within risk area)</i>	3
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	bone marrow transplantation, nutrition, antibiotics, growth factors, spacecraft shielding, body shielding, active dose rate monitors, passive crew dosimeters, biodosimetry, dose management, ground solar particle event warning system
<i>Specific projected countermeasure(s) or mitigation(s)</i>	genetic screening for individual sensitivity, chemical radioprotectants with minimum side effects, cancer progression inhibitors, biological markers for space radiation damage in cells, biophysical computer models for accurate health risk assessment, active neutron spectrometer, active soft x-ray detector for solar particle events, new shielding materials and methods
<i>Relationship to other risks and to other risk areas</i>	Immunology, Infections and Hematology; Environmental Health
<i>Critical Questions:</i>	10.09 What are the cancer risks in humans from spaceflight? (1)
	10.05 Are there unique biological effects associated with HZE's? (2)
	10.06 Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties? (2)
	10.02 Are there adverse synergism's between radiation and other space environmental and biological factors? (1)
	10.03 Are there chemopreventive or biological agents which would mitigate acute or late effects? (3)
	10.07 How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation? (1)
	10.12 What are the effects of age, gender, and inter-individual diversity? (2)
<i>Important References:</i>	NCRP Report No. 98 "Guidance on Radiation Received in Space Activities" (1989)
	NRC Report "Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies" (1997)
	International Commission on Radiological Protection (ICRP) Report 60 "Recommendations of the International Commission on Radiological Protection" (1990)
	Robbins, D. E. and T. C. Yang (1994) Chapter 9. Radiation and Radiobiology. In: Space Physiology and Medicine. Ed. A. E. Nicogossian, C. L. Huntoon, and S. L. Pool. Lea & Febiger, Philadelphia, PA

Risk Data Sheet

<i>Risk number</i>	41
<i>Risk area</i>	Radiation Effects
<i>Risk title</i>	Early or acute effects from radiation exposure
<i>Contributing risk factors</i>	Genetic susceptibility; Stress; Immune function; Environmental toxic agents
<i>Risk description</i>	Ionizing radiation can cause damages in nervous system, intestinal tract, and blood forming organs. The manifestation of the damages in these tissues can be short; within days, weeks and months, depending on radiation dose.
<i>Risk Rank (within risk area)</i>	4
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or mitigation(s)</i>	bone marrow transplantation, nutrition, antibiotics, growth factors, spacecraft shielding, body shielding, active dose rate monitors, passive crew dosimeters, biodosimetry, dose management, ground solar particle event warning system
<i>Specific projected countermeasure(s) or mitigation(s)</i>	genetic screening for individual sensitivity, chemical radioprotectants with minimum side effects, cancer progression inhibitors, biological markers for space radiation damage in cells, biophysical computer models for accurate health risk assessment, active neutron spectrometer, active soft x-ray detector for solar particle events, new shielding materials and methods
<i>Relationship to other risks within risk area and to other risk areas</i>	Environmental Health
<i>Critical Questions:</i>	10.11 What is the acceptable accuracy for risks of acute and late effects in humans from photons to adequately extrapolate to space? (1)
	10.05 Are there unique biological effects associated with HZE's? (2)
	10.06 Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties? (2)
	10.07 How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation? (1)
	10.01 Are the biological effects for protons above 10 MeV sufficiently similar to photons that photon data can be used for their consequences? (3)
	10.10 What are the risks from SPE's and what is their impact on operations, EVAs and surface exploration? (1)
	10.12 What are the effects of age, gender, and inter-individual diversity? (2)
	10.04 Are there differences in response to particles with similar LET, but with different atomic numbers and energies? (2)
	10.08 How do the thickness, design, and material composition of space vehicles affect the internal radiation environment and biological assessment? (1)
	10.03 Are there chemopreventive or biological agents which would mitigate acute or late effects? (3)
<i>Important References:</i>	NCRP Report No. 98 "Guidance on Radiation Received in Space Activities" (1989)
	NRC Report "Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies" (1997)
	International Commission on Radiological Protection (ICRP) Report 60 "Recommendations of the International Commission on Radiological Protection" (1990)
	Robbins, D. E. and T. C. Yang (1994) Chapter 9. Radiation and Radiobiology. In: Space Physiology and Medicine. Ed. A. E. Nicogossian, C. L. Huntoon, and S. L. Pool. Lea & Febiger, Philadelphia, PA

Risk Data Sheet

<i>Risk number</i>	42
<i>Risk area</i>	Radiation Effects
<i>Risk title</i>	Radiation Effects on Fertility, Sterility, and Heredity
<i>Contributing risk factors</i>	Genetic susceptibility; Age; Gender; Environmental toxic agents
<i>Risk description</i>	Human reproductive organs can be sensitive to ionizing radiation. The seminiferous epithelium is among the most radiosensitive tissues in male adults. Human data suggest that long periods of exposure to low dose rates of ionizing radiation can cause sterility and infertility. Also experimental data showed that ionizing radiation can cause genetic alterations in germ cells. The effectiveness of charged particles in inducing fertility, sterility and heredity effects has not been studied in detail.
<i>Risk Rank (within risk area)</i>	5
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	2
<i>Specific current countermeasure(s) or mitigation(s)</i>	bone marrow transplantation, nutrition, antibiotics, growth factors, spacecraft shielding, body shielding, active dose rate monitors, passive crew dosimeters, biodosimetry, dose management, ground solar particle event warning system
<i>Specific projected countermeasure(s) or mitigation(s)</i>	genetic screening for individual sensitivity, chemical radioprotectants with minimum side effects, cancer progression inhibitors, biological markers for space radiation damage in cells, biophysical computer models for accurate health risk assessment, active neutron spectrometer, active soft x-ray detector for solar particle events, new shielding materials and methods
<i>Relationship to other risks within risk area and to other risk areas</i>	Environmental Health
<i>Critical Questions:</i>	10.12 What are the effects of age, gender, and inter-individual diversity? (3)
	10.13 What are the risks associated with fertility, sterility, and hereditary effects as a result of exposure to radiation on long duration missions? (3)
<i>Important References:</i>	NCRP Report No. 98 "Guidance on Radiation Received in Space Activities" (1989)
	NRC Report "Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies" (1997)
	International Commission on Radiological Protection (ICRP) Report 60 "Recommendations of the International Commission on Radiological Protection" (1990)
	Robbins, D. E. and T. C. Yang (1994) Chapter 9. Radiation and Radiobiology. In: Space Physiology and Medicine. Ed. A. E. Nicogossian, C. L. Huntoon, and S. L. Pool. Lea & Febiger, Philadelphia, PA

11.0 Clinical Capabilities

Risk Data Sheet

<i>Risk number</i>	43
<i>Risk area</i>	Clinical Capabilities
<i>Risk title</i>	Trauma and Acute Medical Problems
<i>Contributing Risk factors</i>	Prolonged exposure to microgravity and transitions to altered gravity levels upon landing on planetary surfaces; isolated and confined environment; highly autonomous operations with delayed communications
<i>Risk description</i>	The inability to diagnose and treat illness in microgravity
<i>Risk Rank Order (within risk area)</i>	1
<i>Risk Type (across risks)</i>	I
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or mitigation(s)</i>	Oral isotonic solution, anti-g trousers, thermal control, body orientation and head movement protocols for re-entry, postflight adaptation protocols, inflight aerobic exercise, medications (promethazine for SMS), selection criteria, training, radiation risk management procedures, balanced diet
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Acute and chronic diagnostic and monitoring capabilities; smart medical systems ; advanced medical imaging and telemedicine capabilities; optimal protocols for on-orbit management of injuries
<i>Relationship to other risks within risk area and to other risk areas</i>	Bone Loss, CV Alterations, Environmental Health, Food and Nutrition, Human Behavior and Performance, Immunology, Muscle Alterations and Atrophy, NV Adaptation, Radiation Effects
<i>Critical Questions:</i>	<p>11.01 What are the essential technologies, resources, procedures, skills and training necessary to provide effective advanced life support (CPR, ACLS, ATLS) in space? (1)</p> <p>11.02 What acute and chronic diagnostic and monitoring capabilities (hardware, software, communication and data management capabilities, “smart” systems, and training) is necessary to support acute trauma, surgical and medical intervention in space? (1)</p> <p>11.03 What medical imaging and telemedicine (including medical informatics) capabilities (technology, skills and training) are necessary to support space medicine? (1)</p> <p>11.04 What are the specific techniques, resources, protocols, skills and equipment (technology) necessary to perform surgical intervention and care in the space environment (including options and techniques for anesthesia)? (2)</p> <p>11.05 What are effective methods and technologies for fluid (IV and other) resuscitation and transfusion in space (including blood replacement products)? (2)</p> <p>11.06 What are the optimal treatment methods, technologies, and protocols for the on-orbit management of acute musculoskeletal injuries (including sprains, strains, contusions and fractures)? (2)</p> <p>11.07 What are the most effective options, protocols, and technologies to support patient transport and return to Earth definitive medical care facility? (2)</p> <p>11.08 What are the optimal technologies for supporting an autonomous acute medical response capability in space, including medical informatics, smart medical care systems, on orbit skills maintenance and training? (1)</p> <p>11.09 What are the procedures and protocols for pronouncement of death in space and for the management of a cadaver? (3)</p> <p>11.10 What are the essential technologies, resources, skills, and training necessary to effectively diagnose, treat, and recover patients from likely acute medical emergencies in space including, but not limited to the following: (1)</p> <ul style="list-style-type: none"> - Wounds, lacerations, and burns - Toxic exposure and acute anaphylaxis (including drug reactions) - Acute radiation illness - Dental emergencies - Ophthalmologic emergencies - Gynecologic and urology emergencies - Psychiatric emergencies <p>11.11 What are the technologies, methods, resources, and skills necessary to accomplish chronic care and recovery following an acute medical or surgical event in space? (1)</p> <p>11.12 What technologies are feasible and should be developed to support non-invasive or minimally invasive medical diagnosis and intervention capabilities in space? (1)</p>
<i>Important References:</i>	<p>Medical Policy Board: Medical Procedures and Requirements Document, Third Revision, NASA Headquarters</p> <p>Nicogossian, A.E., Huntoon, C.L., and Pool, S.L., Space Physiology and Medicine, Third Edition, Lea and Febiger, PA., 1994</p>

Risk Data Sheet

<i>Risk number</i>	44
<i>Risk area</i>	Clinical Capabilities
<i>Risk title</i>	Toxic Exposure
<i>Contributing Risk factors</i>	Enclosed spacecraft, chemical leak, increased or altered sensitivity of individuals to environmental agents, allergies, stress, changes in immune system response, inadequate ALS, prolonged dwelling in an enclosed environment
<i>Risk description</i>	Unexpected toxic contamination of spacecraft living environment from chemicals, microbes, or other contaminants inside the living quarters of the space vehicle; or increased sensitivity of individuals to environmental sources of contamination
<i>Risk Rank (within risk area)</i>	2
<i>Risk Type)</i>	II
<i>Current risk mitigation status</i>	3
<i>Specific current countermeasure(s) or mitigation(s)</i>	Sensors, monitoring and control systems for air and water (microbial, chemicals and other contaminants, decontamination protocols
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Advanced sensors, screening, pharmacological treatments, crew screening and selection criteria, adequate nutrition/diet, stress reduction protocols, shielding, protective garments and devices
<i>Relationship to other risks within risk area and to other risk areas</i>	Human Behavior and Performance; Cardiovascular Alterations; Neurovestibular Adaptation; Immunology, Infection and Hematology; ALS; Environmental Health; Radiation Effects
<i>Critical Questions:</i>	11.13 What diagnostic, monitoring and treatment capabilities are essential for management of toxic exposure (acute and chronic)? (1)
	11.14 What crew screening and selection criteria should be developed and implemented to identify individuals who are at increased risk for developing hypersensitivity or allergies to spaceflight compounds, exposures, or payloads? (2)
	11.15 What countermeasures should be developed and implemented to prevent adverse reactions to toxic exposures (e.g. sleep, nutritional, medications, stress reduction, shielding, protective equipment, etc.)? (2)
<i>Important References:</i>	Medical Policy Board: Medical Procedures and Requirements Document, Third Revision, NASA Headquarters
	Nicogossian, A.E., Huntoon, C.L., and Pool, S.L., Space Physiology and Medicine, Third Edition, Lea and Febiger, PA., 1994

Risk Data Sheet

<i>Risk number</i>	45
<i>Risk area</i>	Clinical Capabilities
<i>Risk title</i>	Altered Pharmacodynamics and Adverse Drug Reactions
<i>Contributing risk factors</i>	Polypharmacy (multidrug administration), idiosyncratic tendencies, allergies, pharmacotherapeutic changes in microgravity (e.g., adsorption changes metabolism; drug effect changes-SMS)
<i>Risk description</i>	Drug interactions, adverse reactions to medications given as countermeasures for bone loss, adverse reaction of bone to drugs given for other reasons.
<i>Risk Rank (within risk area)</i>	3
<i>Risk Type</i>	III
<i>Current risk mitigation status</i>	2
<i>Specific current countermeasure(s) or mitigation(s)</i>	none
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Advanced diagnostics and laboratory technologies to predict and manage medication side effects, toxicity and interactions during spaceflight
<i>Relationship to other risks within risk area and to other risk areas</i>	Bone loss, Food and nutrition; Cardiovascular Alterations; Neurovestibular Adaptation; Human Behavior and Performance; Muscle Alterations and Atrophy (coordination of team efforts to minimize medication use and explore alternatives)
<i>Critical Questions:</i>	11.16 What are the effects and implications of spaceflight alterations in human physiology on the absorption, distribution, metabolism, clearance, excretion, clinical efficacy, side effects and drug interactions for clinically useful medications? (2)
	11.17 What technologies are available to provide extended shelf-life pharmaceuticals for long duration spaceflight? (1)
	11.18 What are the side effect and interaction profiles of the commonly use medications in spaceflight, and how should the crew and medical team be trained and prepared to recognize and deal with these issues? (2)
	11.19 What are the most appropriate dosages and routes of administration for the spaceflight clinically useful medications (taking into consideration the answers to question number 11.16)? (1)
	11.20 What diagnostic and laboratory technologies are necessary to predict and manage medication side effects, interactions, and toxicity during spaceflight? (1)
	11.21 What is the effectiveness, indications and risks, and proper utilization of popular non-traditional herbal and nutritional supplements and other alternative therapies (such as homeopathy, etc.)? (3)
<i>Important References</i>	Not specified

Risk Data Sheet

<i>Risk number</i>	46
<i>Risk area</i>	Clinical Capabilities
<i>Risk title</i>	Illness and Ambulatory Problems
<i>Contributing Risk factors</i>	Prolonged exposure to microgravity and transitions to altered gravity levels upon landing on planetary surfaces; isolated and confined environment; highly autonomous operations with delayed communications
<i>Risk description</i>	
<i>Risk Rank (within risk area)</i>	4
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	2
<i>Specific current countermeasure(s) or mitigation(s)</i>	Preflight fitness and quarantine protocols; clinical norms based on epidemiological study
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Risk assessment and acceptability for incidence of illness and injury associated with spaceflight; Improved crew training procedures and systems; telemedicine and medical imaging systems, smart medical systems; improved habitability monitoring systems (microbial, toxicological, radiation, noise and lighting levels); alternative medicine approaches
<i>Relationship to other risks within risk area and to other risk areas</i>	Human Performance; Cardiovascular Alterations; Neurovestibular Adaptation; Muscle Alterations and Atrophy; Food and Nutrition
<i>Critical Questions:</i>	<p>11.22 What are the methods, technologies, and standards for conducting a nominal health and fitness examination in space (including interval history and physical, baseline diagnostics, and data management)? (1)</p> <p>11.23 What are the clinical norms for metabolic and physiologic variables in the space-adapted individual (including clinical laboratory and imaging norms)? (1)</p> <p>11.24 What are the signs, symptoms or abnormal examination findings (including laboratory) associated with diseases observed in space? (1)</p> <p>11.25 What is the risk and incidence of illness and injury associated with spaceflight? (1)</p> <p>11.26 What are the essential technologies, methods, resources, skills and training necessary to support physical examination, diagnosis, monitoring and treatment of illnesses and ambulatory health problems in space (including telemedicine, medical informatics, and smart medical systems)? (2)</p> <p>11.27 What are the technologies, procedures, and resources necessary for management of medical waste products during space? (2)</p> <p>11.28 What are the impacts from and issues related to communication delay on spaceflight health care and telemedicine, and what are the technologies, protocols, and skills necessary for an autonomous health care capability in space as a result of communication delay? (1)</p> <p>11.29 What are the provisions, technologies, methods and skills necessary to support environmental health-related diagnosis and monitoring including microbiological, toxicological, noise and radiation issues? (1)</p> <p>11.30 What are the optimal protocols, technologies, resources, skills and training necessary to diagnose, monitor, treat and recover patients in space from the expected illnesses and ambulatory medical problems, including but not limited to: (1)</p> <ul style="list-style-type: none"> - Orthopedic and musculoskeletal problems - Infectious, hematological and immune-related diseases - Dermatological, ophthalmologic, and ENT problems - Nutritional, metabolic, and endocrine disorders - Dental problems - Gastrointestinal and urologic disorders - Behavioral, fatigue and stress-related problems <p>11.31 What technologies can be developed and implemented to provide computer-assisted, "smart" modeling of the human system in space that can be used for individual patient modeling, monitoring, diagnosis, and prevention (predictive modeling)? (1)</p> <p>11.32 What are alternative approaches to traditional medicine that have potential merit and should be investigated as potential adjunctive therapy for space medicine (such as biofeedback, massage therapy, musculoskeletal manipulation, acupuncture, magnet therapy, etc.)? (3)</p>
<i>Important References:</i>	Not specified

Risk Data Sheet

<i>Risk number</i>	47
<i>Risk area</i>	Clinical Capabilities
<i>Risk title</i>	Development and Treatment of Space-Induced Decompression Sickness
<i>Contributing Risk factors</i>	Deconditioning, Improper EVA operations, Musculoskeletal pain due to bends
<i>Risk description</i>	Inadequate methods available for quality health maintenance and for acute health effects control: differential diagnosis between stress fracture and emboli.
<i>Risk Rank (within risk area)</i>	5
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	Aggressive Pre-breath Protocols
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Portable hyperbaric treatment; monitoring and diagnostic instrumentation, protocols for different levels and categories of decompression illness
<i>Relationship to other risks within risk area and to other risk areas</i>	Bone Loss, Cardiovascular Alterations, Muscle Alterations and Atrophy, Neurovestibular Adaptation, Environmental Health
<i>Critical Questions:</i>	11.33 What are the essential technologies, resources, protocols, skills and training necessary for the diagnosis, monitoring, treatment and recovery of space-related decompression sickness? (1)
	11.34 What is the feasibility and development pathway necessary to provide portable hyperbaric treatment capability in space? (1)
	11.35 What are the diagnostic and monitoring technologies and protocols that will provide effective screening and diagnosis of different levels and categories of decompression illness? What portable diagnostic tool can differentiate between Type I decompression sickness and stress fracture in instances of localized bone or joint pain? (3)
<i>Important References:</i>	Not specified

Risk Data Sheet

<i>Risk number</i>	48
<i>Risk area</i>	Clinical Capabilities
<i>Risk title</i>	Difficulty of Rehabilitation Following Landing
<i>Contributing risk factors</i>	Reentry into higher gravitational forces; fluid loading; exercise, fitness, g-suit, deconditioning, impaired response to orthostatic stress; vestibular contributions to cardioregulatory dysfunction, possible chronic impairment of balance function, muscle performance, endurance or strength impairment
<i>Risk description</i>	Post-landing alterations in cardiovascular, musculoskeletal and neurosensory systems resulting in severe performance decrements, injuries, and long term sequela
<i>Risk Rank (within risk area)</i>	6
<i>Risk Type (across risks)</i>	III
<i>Current risk mitigation status</i>	2
<i>Specific current countermeasure(s) or mitigation(s)</i>	Fluid loading protocols (oral isotonic solutions), anti- g suit, exercise protocols, thermal control, body orientation and limited head movement, inflight exercise protocols
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Aerobic exercise, medication, training, protocols for maintaining urine volume
<i>Relationship to other risks within risk area and to other risk areas</i>	Bone Loss; Cardiovascular Alterations; Food and Nutrition; Human Behavior and Performance; Muscle Alterations and Atrophy; Neurovestibular Adaptation
<i>Critical Questions:</i>	11.36 What are the expected effects and risks of long duration spaceflight related to landing, egress and post-landing performance (in various anticipated gravitational environments)? (1)
	11.37 What are the essential technologies, resources, protocols, skills and training necessary for post-landing performance, recovery and rehabilitation (including psychological, cardiovascular, neurosensory, musculoskeletal, and nutritional)? (1)
	11.38 What pre-landing and pre-egress performance and health parameters should be monitored to assure adequate cardiovascular tone, neurological function, skeletal integrity, muscular strength, and endurance? (2)
	11.39 What are the issues related to and resources required for long term rehabilitation and recovery from long duration spaceflight? (2)
<i>Important References:</i>	Not specified

12.0 Multisystem (Cross Risk) Alterations

Risk Data Sheet

<i>Risk number</i>	49
<i>Risk area</i>	Multisystem (Cross Risk) Alterations
<i>Risk title</i>	Postlanding Alterations in Various Systems Resulting in Severe Performance Decrements and Injuries
<i>Contributing Risk factors</i>	Reentry into higher gravitational forces; Fluid loading; Exercise; Fitness; G-suit; Deconditioning; Impaired response to orthostatic stress; Vestibular contributions to cardioregulatory dysfunction; Possible chronic impairment of balance function; Muscle performance; Endurance or strength impairment; Prolonged exposure to microgravity and transitions to altered gravity levels upon landing on planetary surfaces; isolated and confined environment; highly autonomous operations with delayed communications
<i>Risk description</i>	As the human adapts to the changing conditions of microgravity, alterations in any one physiological system may affect the function of other systems. The primary issue is to understand how post-landing alterations in multiple systems may result in performance decrements or increased injury, and to identify the preventative or rehabilitation strategies for facilitating post-flight recovery of function and performance.
<i>Risk Rank Order (within risk area)</i>	1
<i>Risk Type (across risks)</i>	II
<i>Current risk mitigation status</i>	5
<i>Specific current countermeasure(s) or mitigation(s)</i>	Oral isotonic solution, anti-g trousers, thermal control, body orientation and head movement protocols for re-entry, postflight adaptation protocols, inflight aerobic exercise, medications (promethazine for SMS), selection criteria, training, radiation risk management procedures, balanced diet
<i>Specific projected countermeasure(s) or mitigation(s)</i>	Acute and chronic diagnostic and monitoring capabilities; smart medical systems ; advanced medical imaging and telemedicine capabilities; optimal protocols for on-orbit management of injuries
<i>Relationship to other risks within risk area and to other risk areas</i>	Bone Loss, Cardiovascular Alterations, Food and Nutrition, Human Behavior and Performance, Immunology, Infection and Hematology, Muscle Alterations and Atrophy, Neurovestibular Adaptation
<i>Critical Questions:</i>	12.01 How do alterations in cardiovascular function associated with spaceflight affect the functioning of other systems? (2) 12.02 How do alterations in neural, endocrine, and metabolic function associated with spaceflight affect cardiovascular functioning and the functioning of other organ systems? (2) 12.03 What rehabilitative measures should be applied after mission completion? (2)
<i>Important References:</i>	Medical Policy Board: Medical Procedures and Requirements Document, Third Revision, NASA Headquarters Nicogossian, A.E., Huntoon, C.L., and Pool, S.L., Space Physiology and Medicine, Third Edition, Lea and Febiger, PA., 1994

A-3 CPR Risks, Rank Order, Type and Risk Area

Table A-3.1 Critical Path Roadmap Risks, Rank, Risk Type, and Risk Area

ID ¹	Risk Title ²	Rank ³	Type ⁴	Risk Area ⁵
1	Inability to Maintain Acceptable Atmosphere in Habitable Areas	1	II	Advanced Life Support (ALS)
2	Inability to Provide and Recover Potable Water	2	II	ALS
3	Inadequate Supplies (including maintenance, emergency provisions, and edible food)	2	II	ALS
4	Inability to Maintain Thermal Balance in Habitable Areas	3	II	ALS
5	Inability to Adequately Process Solid Wastes	3	II	ALS
6	Inadequate Stowage and Disposal Facilities for Solid and Liquid Trash Generated During Mission	4	II	ALS
7	Inadequate Nutrition (Malnutrition)	1	II	Food & Nutrition
8	Unsafe Food Systems	2	II	Food & Nutrition
9	Acceleration of Age-Related Osteoporosis	1	I	Bone Loss
10	Fracture & Impaired Fracture Healing	2	II	Bone Loss
11	Injury to Soft Connective Tissue, Joint Cartilage, & Intervertebral Disc Rupture w/ or w/o Neurological Complications	3	III	Bone Loss
12	Renal Stone Formation	4	III	Bone Loss
13	Occurrence of Serious Cardiac Dysrhythmias	1	II	Cardiovascular Alterations
14	Impaired Response to Orthostatic Stress	1	II	Cardiovascular Alterations
15	Diminished Cardiac Function	2	III	Cardiovascular Alterations
16	Manifestation of Previously Asymptomatic Cardiovascular Disease	3	III	Cardiovascular Alterations
17	Impaired Cardiovascular Response to Exercise Stress	4	III	Cardiovascular Alterations
18	Human Performance Failure Because of Poor Psychosocial Adaptation	1	I	Human Behavior & Performance
19	Human Performance Failure Because of Sleep and Circadian Rhythm Problems	2	II	Human Behavior & Performance
20	Human Performance Failure Because of Human System Interface Problems & Ineffective Habitat, Equipment, Design, Workload, or Inflight Information and Training Systems	3	III	Human Behavior & Performance
21	Human Performance Failure Because of Neurobehavioral Dysfunction	4	III	Human Behavior & Performance
22	Immunodeficiency/Infections	1	III	Immunology, Infection & Hematology
23	Carcinogenesis Caused by Immune System Changes	1	III	Immunology, Infection & Hematology
24	Altered Hemodynamic and Cardiovascular Dynamics caused by Altered Blood Components	1	III	Immunology, Infection & Hematology
25	Altered Wound Healing	2	III	Immunology, Infection & Hematology
26	Altered Host-Microbial Interactions	3	III	Immunology, Infection & Hematology
27	Allergies and Hypersensitivity Reactions	3	III	Immunology, Infection & Hematology

¹ Risk Identification number: Unique number assigned to each risk (1-55) used to track/identify each risk

² Risk: The title of each risk

³ The Rank Order assigned to each risk by discipline experts in each risk area; a risk area may have more than 1 risk with the same risk ranking (risk order)

⁴ The Type assigned to each risk by experts; a risk may be Type I, Type II, or Type III depending upon the level of uncertainty regarding both knowledge of the risk itself (its occurrence and severity), and its mitigation status

⁵ The specific risk area representing the risk; there are 12 risk areas in the CPR

Table A-3.1 Critical Path Roadmap Risks, Rank, Risk Type, and Risk Area (Continued)

ID ¹	Risk Title ²	Rank ³	Type ⁴	Risk Area ⁵
28	Loss of Skeletal Muscle Mass, Strength, and/or Endurance	1	II	Muscle Alterations & Atrophy
29	Inability to Adequately Perform Tasks Due to Motor Performance, Muscle Endurance, and Disruption in Structural and Functional Properties of Soft & Hard Connective Tissues of the Axial Skeleton	1	II	Muscle Alterations & Atrophy
30	Inability to Sustain Muscle Performance Levels to Meet Demands of Performing Activities of Varying Intensities	2	II	Muscle Alterations & Atrophy
31	Propensity to Develop Muscle Injury, Connective Tissue Dysfunction, and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength and Muscular Fatigue	3	III	Muscle Alterations & Atrophy
32	Impact of Deficits in Skeletal Muscle Structure and Function on Other Systems	NR	III	Muscle Alterations & Atrophy
33	Disorientation and Inability to Perform Landing, Egress, or Other Physical Tasks, Especially During/After G-Level Changes (Acute spontaneous & provoked vertigo, nystagmus, oscillopsia, poor dynamic visual acuity)	1	II	Neurovestibular Adaptation
34	Impaired Neuromuscular Coordination and/or Strength (Gait ataxia, postural instability)	2	II	Neurovestibular Adaptation
35	Impaired Cognitive and/or Physical Performance Due to Motion Sickness Symptoms or Treatments, Especially During/After G-Level Changes (Including short term memory loss, reaction time increase, drowsiness, fatigue, torpor, irritability, ketosis)	3	III	Neurovestibular Adaptation
36	Vestibular Contribution to Cardiorespiratory Dysfunction (Postlanding orthostatic intolerance, sleep and mood changes)	4	III	Neurovestibular Adaptation
37	Possible Chronic Impairment of Orientation or Balance Function Due to Microgravity or Radiation (Imbalance, gait ataxia, vertigo, chronic vestibular insufficiency, poor dynamic visual acuity)	5	III	Neurovestibular Adaptation
38	Carcinogenesis Caused by Radiation	1	I	Radiation Effects
39	Damage to Central Nervous System from Radiation Exposure	2	II	Radiation Effects
40	Synergistic Effects from Exposure to Radiation, Microgravity and other Spacecraft Environmental Factors	3	II	Radiation Effects
41	Early or Acute Effects from Radiation Exposure	4	II	Radiation Effects
42	Radiation Effects on Fertility, Sterility, and Heredity	5	III	Radiation Effects
43	Trauma and Acute Medical Problems	1	I	Clinical Capabilities
44	Toxic Exposure	2	II	Clinical Capabilities
45	Altered Pharmacodynamics and Adverse Drug Reactions	3	II	Clinical Capabilities
46	Illness and Ambulatory Health Problems	4	III	Clinical Capabilities
47	Development and Treatment of Space-Related Decompression Sickness	5	III	Clinical Capabilities
48	Difficulty of Rehabilitation Following Landing	6	III	Clinical Capabilities
49	Post-landing Alterations in Various Systems Resulting in Severe Performance Decrements and Injuries	1	II	Multisystem (Cross Risk) Alterations
50	Allergies and Hypersensitivity Reactions from Exposure to the Enclosed Spacecraft & Other Environmental Factors	3	II	Environmental Health
51	Inability to Maintain Acceptable Atmosphere in Habitable Areas Due to Environmental Health Contaminants	1	II	Environmental Health
52	Inability to Provide and Recover Potable Water Due to Environmental Health Contaminants	2	II	Environmental Health
53	Inadequate Nutrition (Malnutrition) Due to Inability to Provide and Maintain a Bioregenerative System	1	II	ALS
54	Difficulty of Rehabilitation Following Landing Due to Nutritional Deficiencies	4	III	Food & Nutrition
55	Human Performance Failure Due to Nutritional Deficiencies	3	II	Food & Nutrition

¹ Risk Identification number: Unique number assigned to each risk (1-55) used to track/identify each risk

² Risk: The title of each risk

³ The Rank Order assigned to each risk by discipline experts in each risk area; a risk area may have more than 1 risk with the same risk ranking (risk order)

⁴ The Type assigned to each risk by experts; a risk may be Type I, Type II, or Type III depending upon the level of uncertainty regarding both knowledge of the risk itself (its occurrence and severity), and its mitigation status

⁵ The specific risk area representing the risk; there are 12 risk areas in the CPR

A-4 CPR Risks by Risk Type

All 55 risks are critical risks confronting human exploration missions. The risks differ to the extent in which they are known demonstrated problems with known countermeasures. Type I risks are demonstrated, serious problems with no known countermeasure. Type II risks are suspected to be serious problems with some knowledge of mitigation. Type III risks are also suspected risks but with greater readiness (i.e., testing) of effective risk mitigation.

Table A-3.2 Critical Path Roadmap Risks for Type I, Type II, and Type III Risks

Type I Risks - Four (4)

ID ¹	Risk Title ²	Rank ³	Type ⁴	Risk Area ⁵
9	Acceleration of Age-Related Osteoporosis	1	I	Bone Loss
18	Human Performance Failure Because of Poor Psychosocial Adaptation	1	I	Human Behavior & Performance
38	Carcinogenesis Caused by Radiation	1	I	Radiation Effects
43	Trauma and Acute Medical Problems	1	I	Clinical Capabilities

¹ ID: The unique risk Identification number assigned to each risk (1-55) for tracking and identification purposes.

² Risk: The title of each risk

³ Rank: The Rank Order assigned to each risk by discipline experts in each risk area; a risk area may have more than 1 risk with the same risk ranking (risk order)

⁴ Type: The Type assigned to each risk by experts; a risk may be Type I, Type II, or Type III depending upon the level of uncertainty regarding both knowledge of the risk itself (its occurrence and severity), and its mitigation status

⁵ Risk Area: The specific risk area representing the risk; there are 12 risk areas in the CPR

Table A-3.2 Critical Path Roadmap Risks for Type I, Type II, and Type III Risks
Type II Risks - Twenty-Eight (28)

ID ¹	Risk Title ²	Rank ³	Type ⁴	Risk Area ⁵
1	Inability to Maintain Acceptable Atmosphere in Habitable Areas	1	II	Advanced Life Support (ALS)
2	Inability to Provide and Recover Potable Water	2	II	ALS
3	Inadequate Supplies (including maintenance, emergency provisions, and edible food)	2	II	ALS
4	Inability to Maintain Thermal Balance in Habitable Areas	3	II	ALS
5	Inability to Adequately Process Solid Wastes	3	II	ALS
6	Inadequate Stowage and Disposal Facilities for Solid and Liquid Trash Generated During Mission	4	II	ALS
7	Inadequate Nutrition (Malnutrition)	1	II	Food & Nutrition
8	Unsafe Food Systems	2	II	Food & Nutrition
10	Fracture & Impaired Fracture Healing	2	II	Bone Loss
13	Occurrence of Serious Cardiac Dysrhythmias	1	II	Cardiovascular Alterations
14	Impaired Cardiovascular Response to Orthostatic Stress	1	II	Cardiovascular Alterations
19	Human Performance Failure Because of Sleep and Circadian Rhythm Problems	2	II	Human Behavior & Performance
28	Loss of Skeletal Muscle Mass, Strength, and/or Endurance	1	II	Muscle Alterations & Atrophy
29	Inability to Adequately Perform Tasks Due to Motor Performance, Muscle Endurance, and Disruption in Structural and Functional Properties of Soft & Hard Connective Tissues of the Axial Skeleton	1	II	Muscle Alterations & Atrophy
30	Inability to Sustain Muscle Performance Levels to Meet Demands of Performing Activities of Varying Intensities	2	II	Muscle Alterations & Atrophy
34	Impaired Neuromuscular Coordination and/or Strength (Gait ataxia, postural instability)	2	II	Neurovestibular Adaptation
33	Disorientation and Inability to Perform Landing, Egress, or Other Physical Tasks, Especially During/After G-Level Changes (Acute spontaneous & provoked vertigo, nystagmus, oscillopsia, poor dynamic visual acuity)	1	II	Neurovestibular Adaptation
39	Damage to Central Nervous System from Radiation Exposure	2	II	Radiation Effects
40	Synergistic Effects from Exposure to Radiation, Microgravity and other Spacecraft Environmental Factors	3	II	Radiation Effects
41	Early or Acute Effects from Radiation Exposure	4	II	Radiation Effects
44	Toxic Exposure	2	II	Clinical Capabilities
45	Altered Pharmacodynamics and Adverse Drug Reactions	3	II	Clinical Capabilities
49	Post-landing Alterations in Various Systems Resulting in Severe Performance Decrements and Injuries	1	II	Multisystem (Cross Risk) Alterations
50	Allergies and Hypersensitivity Reactions from Exposure to the Enclosed Spacecraft & Other Environmental Factors	3	II	Environmental Health
51	Inability to Maintain Acceptable Atmosphere in Habitable Areas Due to Environmental Health Contaminants	1	II	Environmental Health
52	Inability to Provide and Recover Potable Water Due to Environmental Health Contaminants	2	II	Environmental Health
53	Inadequate Nutrition (Malnutrition) Due to Inability to Provide and Maintain a Bioregenerative System	1	II	ALS
55	Human Performance Failure Due to Nutritional Deficiencies	3	II	Food & Nutrition

¹ ID: The unique risk Identification number assigned to each risk (1-55) for tracking and identification purposes.

² Risk: The title of each risk

³ Rank: The Rank Order assigned to each risk by discipline experts in each risk area; a risk area may have more than 1 risk with the same risk ranking (risk order)

⁴ Type: The Type assigned to each risk by experts; a risk may be Type I, Type II, or Type III depending upon the level of uncertainty regarding both knowledge of the risk itself (its occurrence and severity), and its mitigation status

⁵ Risk Area: The specific risk area representing the risk; there are 12 risk areas in the CPR

Table A-3.2 Critical Path Roadmap Risks for Type I, Type II, and Type III Risks

Type III Risks - Twenty-Three (23)

ID ¹	Risk Title ²	Rank ³	Type ⁴	Risk Area ⁵
11	Injury to Soft Connective Tissue, Joint Cartilage, & Intervertebral Disc Rupture w/ or w/o Neurological Complications	3	III	Bone Loss
12	Renal Stone Formation	4	III	Bone Loss
15	Diminished Cardiac Function	2	III	Cardiovascular Alterations
16	Manifestation of Previously Asymptomatic Cardiovascular Disease	3	III	Cardiovascular Alterations
17	Impaired Cardiovascular Response to Exercise Stress	4	III	Cardiovascular Alterations
20	Human Performance Failure Because of Human System Interface Problems & Ineffective Habitat, Equipment, Design, Workload, or Inflight Information and Training Systems	3	III	Human Behavior & Performance
21	Human Performance Failure Because of Neurobehavioral Dysfunction	4	III	Human Behavior & Performance
22	Immunodeficiency/Infections	1	III	Immunology, Infection & Hematology
23	Carcinogenesis Caused by Immune System Changes	1	III	Immunology, Infection & Hematology
24	Altered Hemodynamic and Cardiovascular Dynamics caused by Altered Blood Components	1	III	Immunology, Infection & Hematology
25	Altered Wound Healing	2	III	Immunology, Infection & Hematology
26	Altered Host-Microbial Interactions	3	III	Immunology, Infection & Hematology
27	Allergies and Hypersensitivity Reactions	3	III	Immunology, Infection & Hematology
31	Propensity to Develop Muscle Injury, Connective Tissue Dysfunction, and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength and Muscular Fatigue	3	III	Muscle Alterations & Atrophy
32	Impact of Deficits in Skeletal Muscle Structure and Function on Other Systems	NR*	III	Muscle Alterations & Atrophy
35	Impaired Cognitive and/or Physical Performance Due to Motion Sickness Symptoms or Treatments, Especially During/After G-Level Changes (Including short term memory loss, reaction time increase, drowsiness, fatigue, torpor, irritability, ketosis)	3	III	Neurovestibular Adaptation
36	Vestibular Contribution to Cardiorespiratory Dysfunction (Postlanding orthostatic intolerance, sleep and mood changes)	4	III	Neurovestibular Adaptation
37	Possible Chronic Impairment of Orientation or Balance Function Due to Microgravity or Radiation (Imbalance, gait ataxia, vertigo, chronic vestibular insufficiency, poor dynamic visual acuity)	5	III	Neurovestibular Adaptation
42	Radiation Effects on Fertility, Sterility, and Heredity	5	III	Radiation Effects
46	Illness and Ambulatory Health Problems	4	III	Clinical Capabilities
47	Development and Treatment of Space-Related Decompression Sickness	5	III	Clinical Capabilities
48	Difficulty of Rehabilitation Following Landing	6	III	Clinical Capabilities
54	Difficulty of Rehabilitation Following Landing Due to Nutritional Deficiencies	4	III	Food & Nutrition

¹ ID: The unique risk Identification number assigned to each risk (1-55) for tracking and identification purposes.

² Risk: The title of each risk

³ Rank: The Rank Order assigned to each risk by discipline experts in each risk area; a risk area may have more than 1 risk with the same risk ranking (risk order)

⁴ Type: The Type assigned to each risk by experts; a risk may be Type I, Type II, or Type III depending upon the level of uncertainty regarding both knowledge of the risk itself (its occurrence and severity), and its mitigation status

⁵ Risk Area: The specific risk area representing the risk; there are 12 risk areas in the CPR

* (NR: not rated by discipline risk area team)